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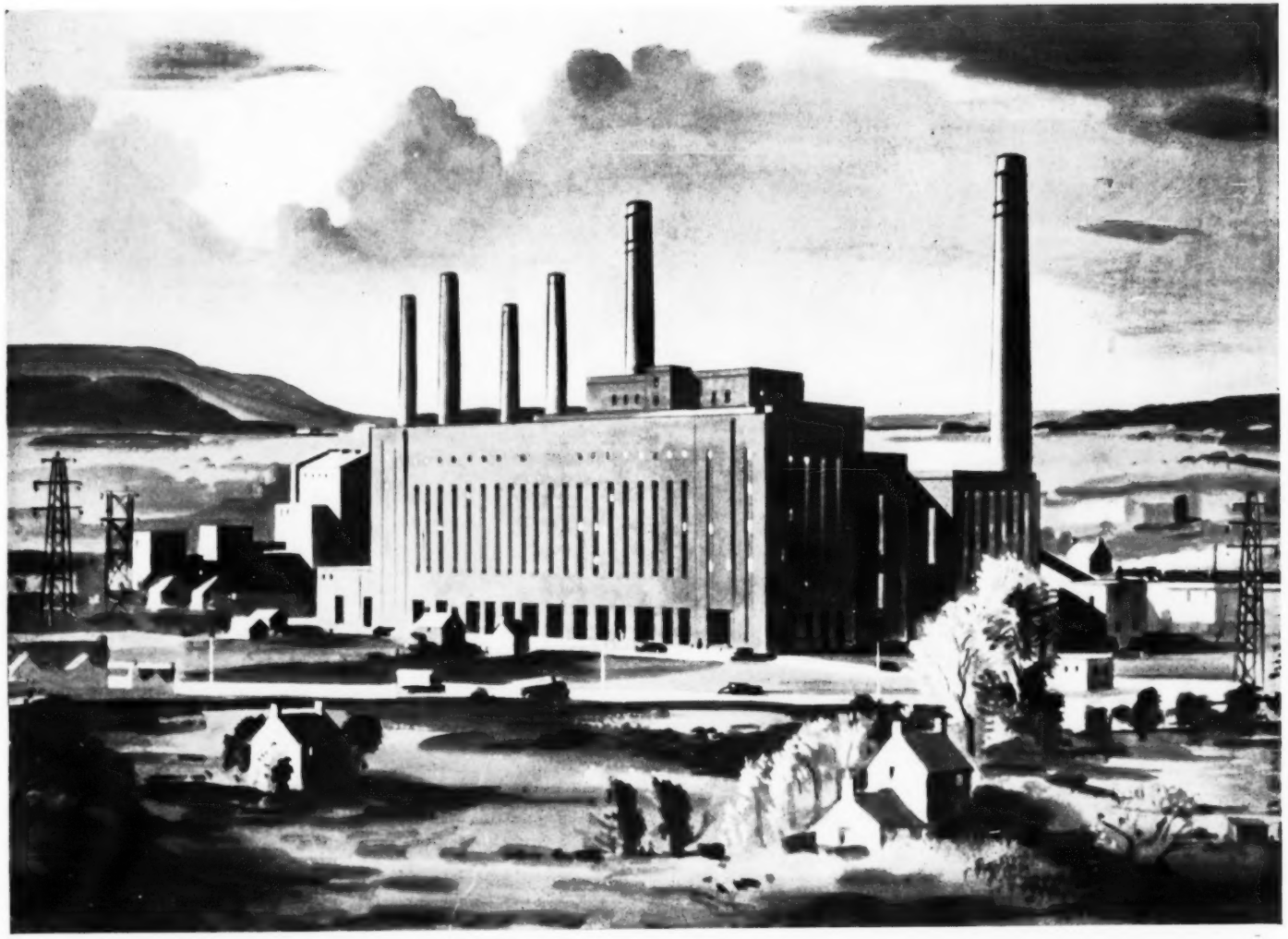


Stourport generating station of the British Electricity Authority, Midlands Division

Stourport "B" Generating Station of the British Electricity Authority, Midlands Division

By L. C. HOOKINS, A.M.I.Mech.E., and W. E. PETERS,
Steam Turbine Design Department,
and V. J. VICKERS, B.Sc.(Eng.), A.C.G.I., D.I.C., Machine Design Department.

ANOTHER STEP TOWARDS the balancing of electrical supply and demand, and towards the elimination of power cuts, was taken during the summer of 1950 in the commissioning of the new 60 MW generating plant in Stourport "B" Station.

The original "A" station at Stourport was built by the Shropshire, Worcestershire & Staffordshire Electric Power Company which subsequently became one of the Edmundsons group, and it was during this latter period that the plans for the "B" station were first laid down and the specifications for the plant prepared. After vesting day the engineering of the new plant was placed in the hands of Messrs Ewbank & Partners, Consulting Engineers, whose staff was drawn principally from the Engineering Department of the Edmundsons Corporation before taking over by the B.E.A.

From its first conception the "B" station was planned to represent the most up-to-date British practice; the steam conditions selected were 1,250 lb/sq. in., 950° F., and the final feed temperature 460° F. with five stages of heating. The vacuum at the exhaust flange is 28.75 in. Hg.

STEAM TURBINE

The turbine (as will be seen from the section shown in Fig. 1) is of the three-cylinder type, comprising an H.P. and an I.P. turbine followed by a double flow L.P. turbine which exhausts to twin condensers. It drives, in tandem, at 3,000 r.p.m., a 55.5 MW main alternator and a 4.5 MW house alternator.

The steam supply is through two centre pressure stop valves to two forged steel steam chests arranged symmetrically about the turbine, each chest being provided with an emergency trip valve and a governing valve. The chests operate in parallel. Each chest is connected to the high pressure turbine by two pipes, one to the top of the casing and one to the bottom. Adequate flexibility in this piping, combined with the symmetry of the arrangement, ensures that pipe thrusts largely cancel out, thus relieving the turbine of any undue thrust loads from this source.

As it is intended that at least during the early part of its life this unit is to act as a base load machine, the most economical load coincides with the maximum continuous load, and throttle governing only is provided. This has the incidental advantage of simplifying the high pressure casing casting, and also of reducing diaphragm stresses throughout the machine.

The H.P. and I.P. turbines are of the impulse type, with rotors machined out of solid forgings and with steel diaphragms of built-up construction. The L.P. turbine is provided with reaction blading except at the inlet, where the use of a double flow impulse stage enables a considerable heat drop to be utilised without leakage losses.

The double-flow low pressure rotor is of the built-up construction, consisting of forged steel discs shrunk on to the shaft.

The couplings throughout are of the flexible type with generous axial float, and as each turbine is provided with its own thrust block, differential expansions are confined to each individual turbine. In this connection it should be noted that the H.P. and I.P. turbine thrust blocks can be moved by a slight amount in an axial direction while the turbine is in operation so that the effects of differential expansions during starting or unloading periods can be minimised. With the same object in view, when starting, the flanges of the H.P. cylinder are provided with controllable steam heating.

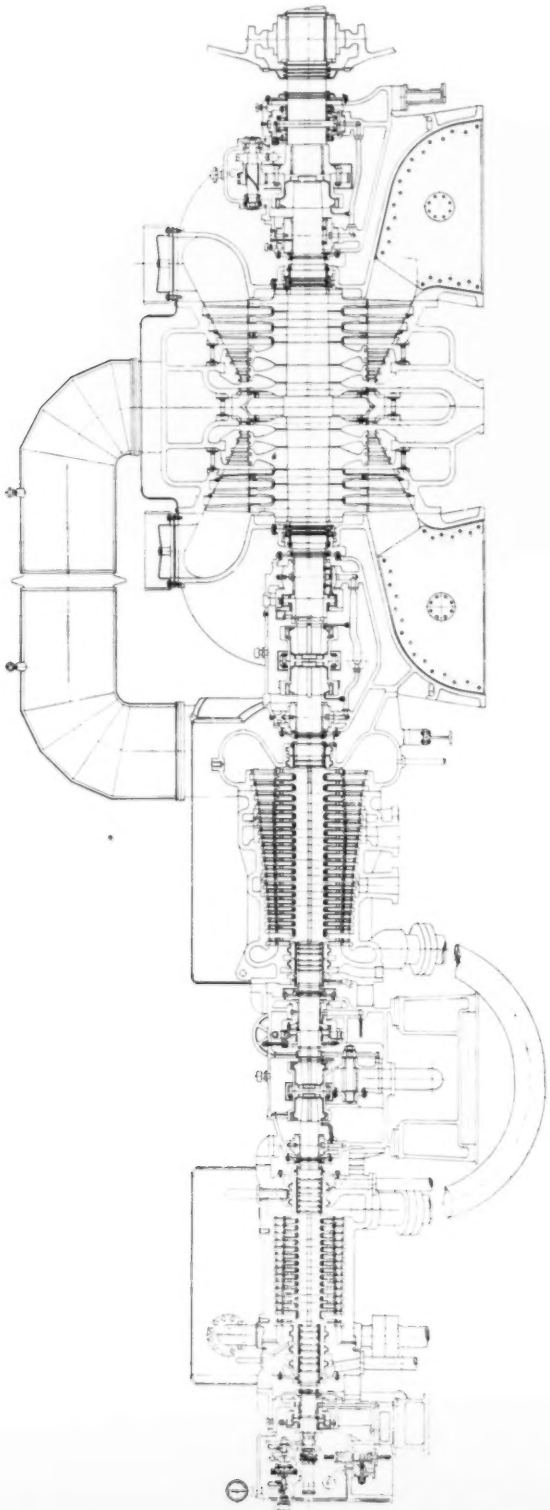


Fig. 1. Sectional arrangement of the turbine

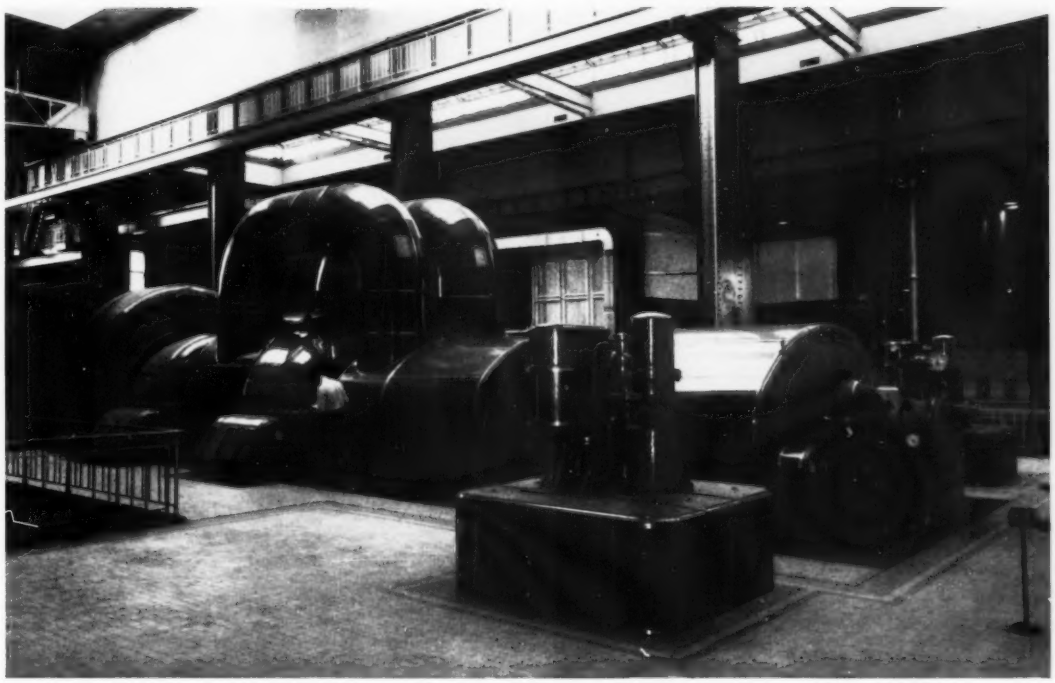


Fig. 2. The complete turbo-alternator set with the steam chest in the foreground, and the vacuum load limiting control panel on the near side of the steam end pedestal

Blading and Glands

The blading is of stainless iron throughout with the exception of the last two rows on the L.P. rotor which are of high tensile manganese nickel steel, chromium plated. This steel is particularly suitable for withstanding the heating necessary when attaching lacing wires by silver soldering, without air hardening and the consequent risk of the formation of hairline cracks.

All the running blading is machined out of solid bar material and has integral roots. The blade fixings are of various types suited to the stresses imposed in service, but mention may be made of the fixings of the long blades of the last two rows of the L.P. turbine. These are of the "side-entry" type in which each root is held in a separate groove in the disc head, the grooves being cut across the head in an approximately axial direction. The effect of this is that bending stresses are virtually eliminated both in the blade root and in the disc head. The total resultant stress at this vital point is therefore much reduced.

The glands throughout the machine are of the labyrinth type, steam packed, and the gland system is so arranged that when the machine is on load the leakage steam from the various high pressure glands is conducted to lower pressure stages of the turbine where it performs useful work. The vacuum glands of the L.P. turbine are packed by steam taken from the I.P. cylinder at a moderate temperature. The system is also so arranged that during starting and stopping periods the glands are fed by steam at a temperature suited to the existing temperature of the glands at the time.

Governing

An hydraulic system of governing and load regulation is employed, a small high-speed centrifugal governor actuating relays which vary the oil

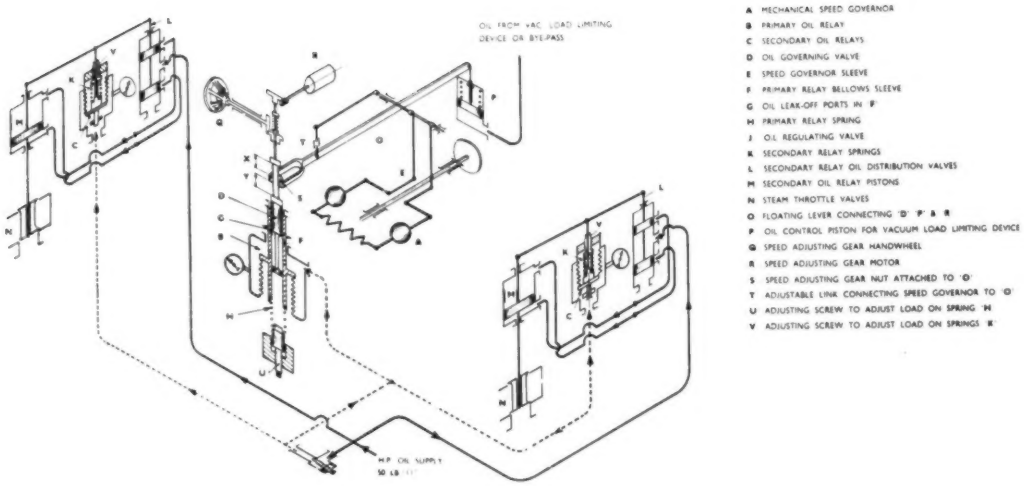

OIL FROM VAC. LOAD LIMITING DEVICE OR BYE-PASS
M.P. OIL SUPPLY
A MECHANICAL SPEED GOVERNOR
B PRIMARY OIL RELAY
C SECONDARY OIL RELAYS
D OIL GOVERNING VALVE
E SPEED GOVERNOR SLEEVE
F PRIMARY RELAY BELLOWS SLEEVE
G OIL LEAK-OFF PORTS IN 'F'
H PRIMARY RELAY SPRING
J O.I. REGULATING VALVE
K SECONDARY RELAY SPRINGS
L SECONDARY RELAY OIL DISTRIBUTION VALVES
M SECONDARY OIL RELAY PISTONS
N STEAM THROTTLE VALVES
O FLOATING LEVER CONNECTING 'D' 'P' & 'R'
P OIL CONTROL PISTON FOR VACUUM LOAD LIMITING DEVICE
Q SPEED ADJUSTING GEAR HANDWHEEL
R SPEED ADJUSTING GEAR MOTOR
S SPEED ADJUSTING GEAR NUT ATTACHED TO 'O'
T ADJUSTABLE LINK CONNECTING SPEED GOVERNOR TO 'O'
U ADJUSTING SCREW TO ADJUST LOAD ON SPRING 'H'
V ADJUSTING SCREW TO ADJUST LOAD ON SPRINGS 'K'

Fig. 3. Diagrammatic arrangement of the hydraulic governor gear

pressure in the main servo-motors of the steam control valves.

The arrangement is shown diagrammatically in Fig. 3. It will be seen that a movement of the governor occasioned by a change of load causes a corresponding movement in the oil governing valve D which opens or closes the oil leak-off ports G in the bellows sleeve F, thereby varying the oil pressure in the primary and secondary oil relays B and C. The oil is supplied under pressure to these relays through an oil regulating valve J.

The variation in oil pressure in the secondary relays C is reflected in a movement of their bellows working in conjunction with springs K, thus opening or closing the steam throttle valves N through the medium of the oil distribution valves L and relay pistons M.

Speed changes, or, when synchronised with other plant, load adjustments, are effected by screwing the spindle of the oil governing valve D through a nut on the end of the lever O. This can be done either by hand by means of the handwheel Q or by remote control by means of the motor R.

The emergency governor gear can be actuated by two mechanical overspeed governors of the unbalanced ring type, by an electrical overspeed governor, by hand trip at the turbine, or by electrical trip operated from the control room. In each case both the emergency valves and the governing valves are closed and non-return valves on the high pressure bled steam lines are closed electrically, thus preventing reverse flow of high pressure steam into the turbine.

Lubrication

The lubrication system is shown diagrammatically in Fig. 4. It will be seen that the system comprises an oil tank, a main oil pump housed in the I.P. pedestal and driven from the main turbine shaft through helical gearing, and three motor-driven gear type auxiliary oil pumps. The first of these is a full duty A.C. driven pump for use when starting up and shutting down, and in emergencies. It is automatically controlled to come into action, or shut down, when the oil pressure in the main relay system falls below, or rises above, a predetermined pressure.

The next auxiliary pump is D.C. driven from the station battery. This pump supplies oil for lubrication purposes only and is automatically brought into action when the pressure of the oil to the bearings falls below a certain value. Alarm signals are given when each of these two pumps is brought into service automatically.

The third auxiliary pump is for use during barring periods and so supplies oil for lubrication purposes only. It is A.C. driven and hand controlled.

The oil system also contains an oil jacking pump and three oil coolers (Fig. 5).

Oil is drawn from the tank and delivered through a non-return valve to the distribution box. This is fitted with a relief valve set at about 60 lb/sq. in., through which surplus oil is returned to the tank. Pressure oil is supplied to the governor relay gear from the distribution box.

Oil for lubricating purposes passes through a pressure reducing valve to the coolers and thence to the bearings at a pressure of about 15 lb/sq. in. Oil from the bearings passes through sight boxes to the bus return pipe which conveys it back to the oil tank via strainers.

Oil alarm signals are transmitted to the main control board should the temperature of the return oil from any bearing rise to an excessive value.

Barring Gear

Electrically driven barring gear is provided in order to reduce to a minimum any risk of the turbine rotors distorting due to uneven heating or cooling whilst the set is shut down. The gear is put into operation by hand but is thrown out automatically when the turbine speed under steam exceeds that of the gear.

High pressure oil jacking is provided at the L.P. turbine and alternator bearings, ensuring that each of these journals is supported by a continuous oil film before barring commences, until the journal speed is sufficient to maintain an oil film when supplied by the auxiliary oil pump.

Damage to the bearings is thus avoided and the starting effort required from the barring motor much reduced.

Supervisory and Protective Equipment

In order to obtain close control during starting

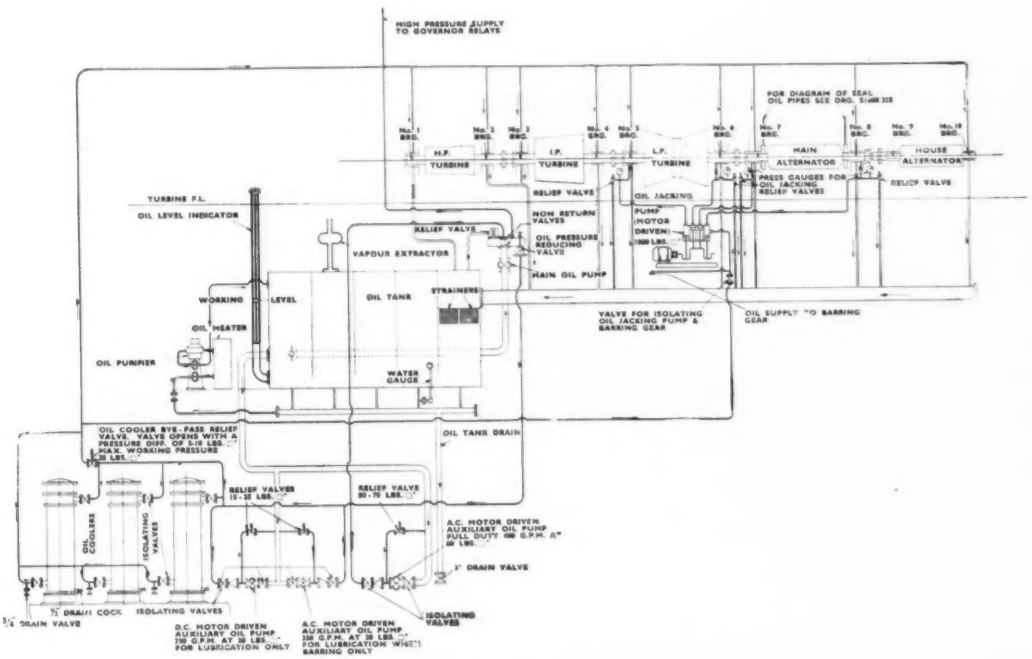

HIGH PRESSURE SUPPLY TO GOVERNOR RELAYS
FOR DIAGRAM OF SEAL OIL PIPES SEE DRG.
No. 1 BRG.
No. 2 BRG.
No. 3 BRG.
No. 4 BRG.
No. 5 BRG.
No. 6 BRG.
No. 7 BRG.
No. 8 BRG.
No. 9 BRG.
No. 10 BRG.
H.P. TURBINE
I.P. TURBINE
L.P. TURBINE
MAIN ALTERNATOR
HOUSE ALTERNATOR
PRESS GAUGES FOR OIL JACKING RELIEF VALVES
RELIEF VALVE
OIL JACKING PUMP (MOTOR DRIVEN)
NON RETURN VALVES
OIL PRESSURE REDUCING VALVE
MAIN OIL PUMP
VAPOUR EXTRACTOR
TURBINE F.L.
OIL LEVEL INDICATOR
WORKING LEVEL
OIL HEATER
OIL TANK
STRAINERS
VALVE FOR ISOLATING OIL JACKING PUMP & BARRING GEAR
OIL SUPPLY TO BARRING GEAR
OIL PURIFIER
WATER GAUGE
OIL COOLER BYE-PASS RELIEF VALVE. VALVE OPENS WITH A PRESSURE DIFF. OF 5-10 LBS. MAX. WORKING PRESSURE 25 LBS.
OIL TANK DRAIN
RELIEF VALVES 15-25 LBS.
RELIEF VALVES 50-70 LBS.
OIL COOLERS
ISOLATING VALVES
A.C. MOTOR DRIVEN AUXILIARY OIL PUMP PULL DUTY 600 G.P.M. AT 20 LBS.
1" DRAIN VALVE
½" DRAIN COCK
ISOLATING VALVES
¾" DRAIN VALVE
D.C. MOTOR DRIVEN AUXILIARY OIL PUMP. 700 G.P.M. AT 20 LBS. FOR LUBRICATION ONLY
A.C. MOTOR DRIVEN AUXILIARY OIL PUMP. 300 G.P.M. AT 20 LBS. FOR LUBRICATION WHEN BARRING ONLY
ISOLATING VALVES

Fig. 4. Diagram of the oil system

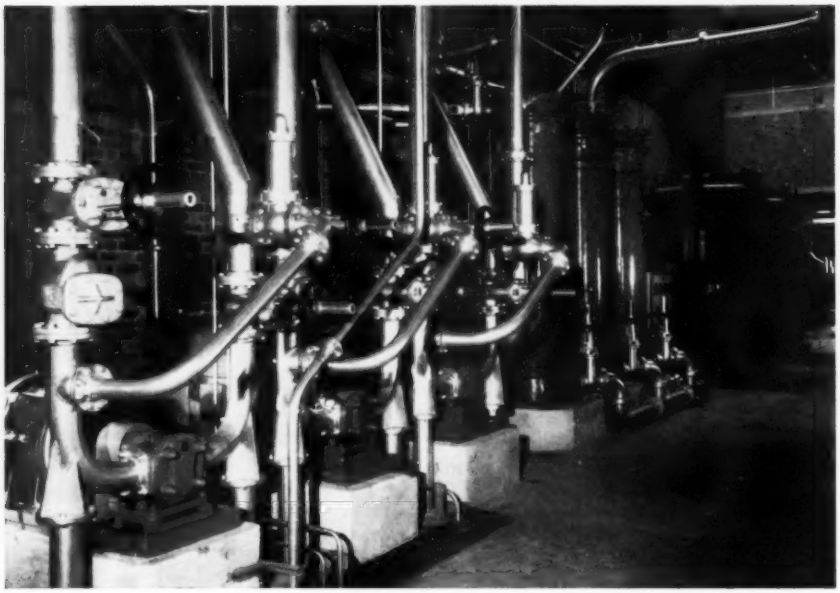


Fig. 5.

A general view of the lubricating oil pumps and three 50 per cent. duty vertical oil coolers. Condenser circulating water pumps are in the right background

and stopping periods, the set is equipped with so-called supervisory instruments which give reliable information as to the condition and behaviour of various components, particularly in the H.P. turbine. The following instruments are included under this category:—

An electrical speed indicator, additional to the usual mechanical tachometer, which indicates and records speeds from about 100 r.p.m. upwards.

An expansion meter, located at the H.P. pedestal, which indicates and records the cumulative axial expansion or contraction of the turbine between the anchorage at the L.P. turbine and the H.P. pedestal. This indication shows whether the machine is responding normally to temperature changes as loads vary. The instrument operates on the solenoid principle.

Vibration pick-ups are mounted on the H.P. and I.P. pedestals, and transverse vibrations at these positions are amplified electrically to indicating and recording instruments.

A Shaft Eccentricity Indicator and Recorder

This instrument is of great importance when starting up, particularly if the turbine is in a half warm condition after a comparatively short shut-down period. It indicates and records any eccentricity there may be at one position on the H.P. rotor, thus showing if the rotor is bowed due to unequal cooling. This information is obtained while the rotor is revolving at a low speed, before any harm is done, and the operators are thereby warned not to increase speed until the shaft has straightened.

A relative expansion indicator and recorder is provided which shows the relative expansion between the H.P. casing and the rotor, and is of especial importance when starting up or shutting down the machine. Suitable action by the operators dictated by the readings obtained on this instrument enables axial clearances in the H.P. turbine to be kept at safe values even though the casing and rotors are expanding or contracting at different rates.

The last two instruments described operate on the principle of introducing the distance to be measured as a variation in an air-gap controlling the reactance of an inductive circuit.

Two throttle valve position indicators are provided, one for each throttle valve, which show the positions of the valves at the supervisory cubicle

and in the control room. These instruments, which indicate but do not record, work on the solenoid principle.

Governor Anticipatory Gear

Steam turbines operating under very high steam pressures store up a considerable amount of energy at any but partial loads by virtue of the actual weight of steam which the turbine holds at any instant. With the comparatively light rotors of high speed machines this stored energy can cause overspeeding if the load is suddenly lost for any reason. In addition, the flow of steam into the turbine is not checked fully until the permanent speed variation, full load to no load, has been reached, that is, when the governing valves are closed. The combination of these speed increases may be sufficient to cause the emergency governor to trip and cause delay in getting the set back on the bars. With the object of preventing the governor permanent speed variation in the event of a sudden loss of load, a governor anticipating device is fitted which closes the governing valves immediately a drop in load of sufficient magnitude occurs. The equipment consists of a solenoid which, when energised, releases the oil pressure in the governing hydraulic system, thus closing the turbine throttle valves.

The solenoid circuit is completed by the contacts of a steam pressure relay which close above a pressure corresponding to about 50 per cent. load, and the contacts of wattmeter relays which close below about 10 per cent. load. The effect is that if the set is loaded above 50 per cent., and there is a sudden complete loss of load, the contacts of the wattmeter relays will close, and those of the steam pressure relay being already closed, the solenoid will operate to shut off steam.

This will not happen if the loss of load commences at a load less than 50 per cent. as the steam relay contacts will in that case be open; nor will it happen if the loss of load is not complete within 10 per cent. as the wattmeter relays are open until 10 per cent. load is reached.

The oil valve when operated by the solenoid is held open by a spring loaded plunger and this arrangement enables the speeder gear to be operated so as to bring the governing valves to the no load position after the fault has been cleared but before the plunger is released. Otherwise there is a risk that when the fault has been cleared, the original load might be suddenly thrown on to the set.

Vacuum Unloading and Trip Gear

The condenser is automatically protected against excessive temperature and internal pressure if loss of vacuum should occur. A vacuum load limiting device is provided which gradually unloads the set by action on the governor gear, commencing to unload when the vacuum has fallen to about 23 in. and continuing until, at about 17 in., all load has been removed. Further increase in the pressure in the condenser to a pressure of 10 to 12 lb. absolute causes a low vacuum trip to operate on the emergency gear, closing the emergency and governing valves.

In the remote contingency of these two safety devices failing to operate, further protection is afforded to the condenser by the provision of explosion doors, one on the top of each exhaust hood. Each consists of a sheet lead diaphragm supported on the vacuum side by a support plate resting on a grid, and clamped round its edge between the explosion door guard and the grid. During normal operation the support plate and grid take the atmospheric load, but should the load be reversed by excessive pressure developing in the exhaust space, then the support plate will rupture the lead diaphragm round its edge, thus opening the exhaust space to atmosphere. The diaphragm centre and support plate, after sufficient movement upwards, are retained within the guard by cross pieces, and the escaping steam is directed upwards by the guard.

Blade Washing

If it should happen that deposits are formed in the turbine, the necessary fittings and connections are provided to supply the turbine with dry, saturated steam in order to wash away such deposits. This operation is carried out at no load and at a considerably reduced speed.

FEED HEATING SYSTEM

The feed water is heated to a final temperature at M.C.R. conditions of 460° F. in five main stages of feed heating, using steam bled from the turbine.

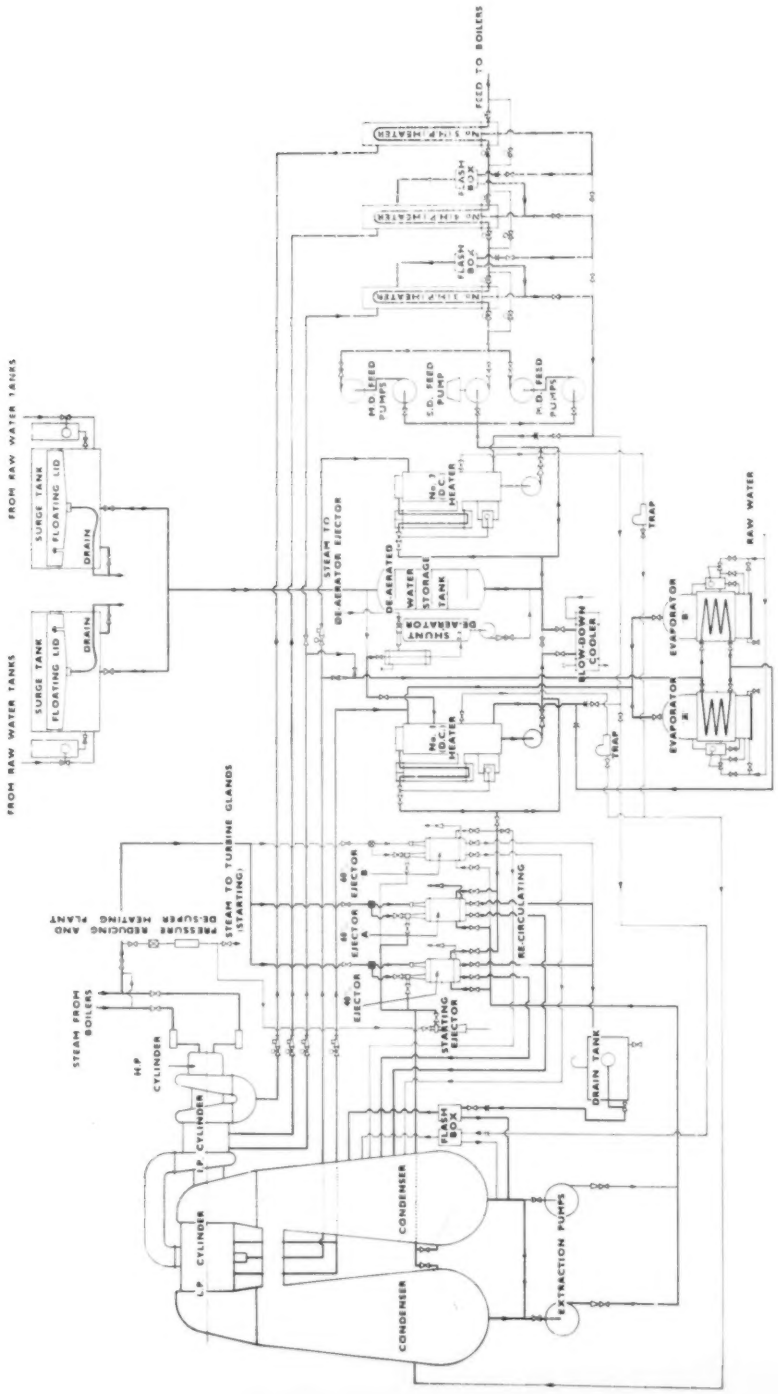


Fig. 6. Simplified feed diagram

The heating scheme, illustrated in Fig. 6, consists of two low pressure direct contact type heaters arranged on the suction side of the boiler feed pumps, and three high pressure surface type heaters on the discharge side of the feed pumps.

L.P. Heaters

The direct contact type heaters, which are of Messrs. Hick Hargreaves manufacture, each operate on the recirculating principle, the amount of condensate entering the heaters being governed by a series of spray nozzles contained in the head of the heater. The condensate is heated by bled steam fed directly into the heater body. The spray nozzles and the heater extraction pumps are designed to handle a quantity in excess of the normal M.C.R. requirements, thus providing a reserve of deaerated water to meet slight increases in demand by the boiler feed pumps. Under normal conditions, the excess water delivered by the heater pumps recirculates back to the heater inlets. Should a heater pump fail at any time, the heater is automatically by-passed through the recirculating connection without the operation of any automatic valve. Flooding of a heater is prevented by a float-operated inlet valve, and if this fails to operate, then by an emergency drain trap.

The condensate line between the two D.C. heaters is connected by a surge leg to two surge tanks, each having a capacity of about 20,000 gallons, so that excess water can be passed to the tanks or supplementary water drawn from the tanks into the system, according to the demands of the boiler feed pumps.

Deaeration

In view of the high steam conditions, very careful consideration has had to be given to the exclusion of oxygen from the feed water. While the machine is running, the most likely period for oxygen to enter the feed water would be under load changing conditions, due to the possibility of introducing water containing oxygen from the surge tanks. To overcome this, a storage tank having a capacity of 8,500 gallons has been arranged in the bottom of the surge leg, which serves as storage for deaerated water. Excess water from the condensate system which has been deaerated in the condenser and in the first D.C. heater is stored in this tank ready for peak demands, and any sustained demand for feed water in excess of the condensate quantity is supplied from this deaerated water storage tank.

To assist in maintaining the water in the storage tank in a deaerated state, the two surge tanks are each provided with floating lids to prevent the absorption of oxygen over the comparatively large surface area of the water contained in the tanks. The floating lids are arranged to cover practically the whole surface of the water, flexible rubber seals being provided between the sides of the tank and the floating lids. Small vent connections are provided on the floating lids to prevent pressure building up in the tanks when excess condensate is admitted, and a vacuum being created when water is drawn off.

Emergency water is introduced into the surge tanks from the raw water tanks by means of a float-operated valve which is set to open when the water in the surge tank falls to a predetermined low level. Any water introduced from the raw water tanks will be cold, and will therefore contain oxygen. A connection is however provided on the surge leg above the deaerated water storage tank, which enables water to be recirculated from the surge leg through the first D.C. heater and back to the base of the deaerated water storage tank, thus enabling the water in the storage tank to be maintained in a deaerated state.

In order to safeguard the boilers during off-load periods and also to provide a supply of deaerated water during the starting-up period, a small deaerating plant is arranged in a shunt connection across the deaerated water storage tank. Water is drawn into the deaerator from the top of the storage tank, and after deaeration it is discharged by a small pump into the base of the storage tank. The deaerator is of the simple spray type in which a vacuum is maintained by a steam operated air ejector, the discharge from which passes to a small feed heater, the heat in the steam being absorbed by the incoming feed to the deaerator. A reserve of deaerated water is thus built up in the deaerated water storage tank ready for starting up or topping the boilers during the off-load periods.

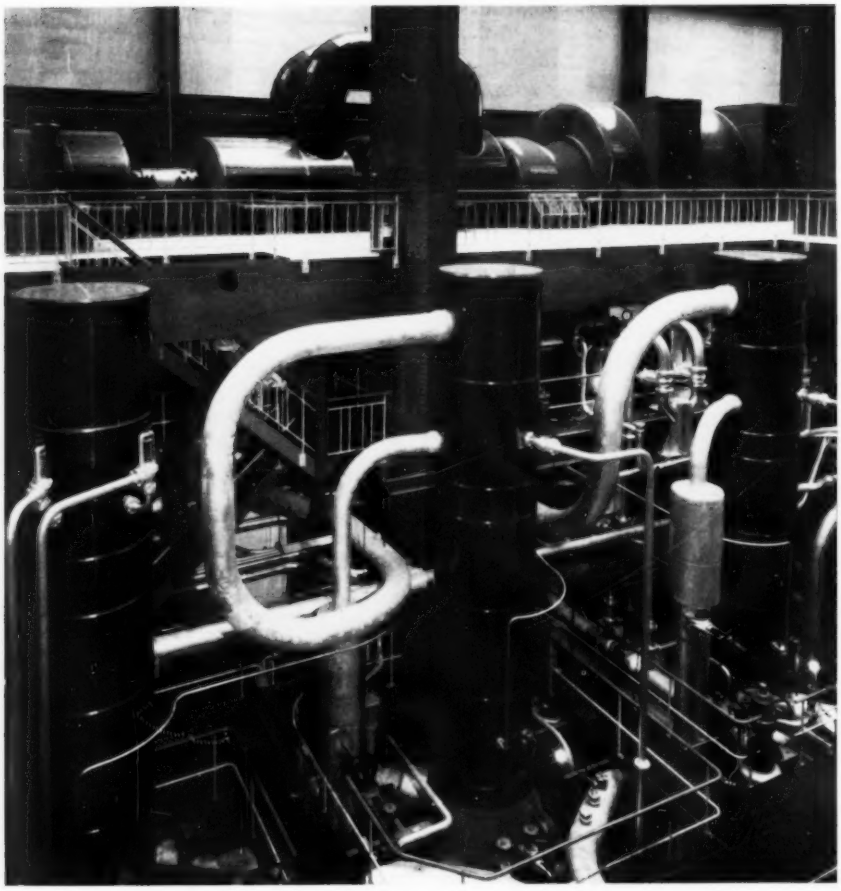


Fig. 7.

The H.P. heater gallery, showing the three inverted type high pressure feed heaters of the five-stage feed heating system

H.P. Heaters

The three high pressure heaters (see Fig. 7) are of the vertical inverted " U " tube type with forged steel water heads fitted with internal manhole covers. One end of the water head forms the tubeplate, and the tubes which are of cupro-nickel are roller expanded into the tubeplate. Special handling gear is provided for removing the internal covers of the water head.

The high pressure heaters are designed for a working pressure on the water side of 2,270 lb/sq. in.

The drains from the H.P. heaters are cascaded from one to another and the combined H.P. heater drains are cascaded to No. 2 D.C. heater where they are pumped forward by the heater drains pump. In the event of No. 2 D.C. heater being out of commission, the H.P. heater drains are by-passed to No. 1 D.C. heater, and in the event of both D.C. heaters being out of service the drains are by-passed to the main condenser.

Evaporators

Two single-effect bled steam evaporators are provided, each capable of producing a make-up equal to approximately $2\frac{1}{2}$ per cent. of the steam consumption of the turbine at M.C.R. The heating steam for the evaporators is taken from the bleeder pipe supplying steam to No. 2 D.C.

heater and the vapour produced is condensed in No. 1 direct contact heater. An alternative steam connection is provided for the evaporators from the bleeder pipe to the first H.P. heater, in order to boost the make-up during light load periods.

Condenser

The main condenser is of the twin shell type (Fig. 8) so arranged that one shell can be shut down for cleaning with the machine running at reduced load. The tubes are arranged in accordance with the Company's standard " ribbon " formation which ensures efficient distribution of the steam over the whole condensing surface and offers minimum resistance to the passage of steam. The tubes are of Admiralty mixture, 1 in. outside diameter, and a distinctive feature is the method of tube fixing, the tubes being expanded into the tubeplates at both ends, so that no tube packings are used. An expansion piece is formed in one end of the shell of the condenser to take up any differential expansion. This expansion piece is fitted at the return end of the condenser so that movement is not restrained by the circulating water pipes, and in order that the weight of the return end waterway shall not deform the expansion piece, the waterway is supported from a bracket on the neck of the condenser. The condenser tubes are slightly bowed to provide complete drainage when emptying the condenser waterways.

Pumps

The main circulating water pumps are of the axial flow type. Two pumps are provided, each pump delivering the circulating water through one shell of the condenser. The system is syphonic and an Aquair pump is provided to maintain maximum syphonic assistance.

Auxiliary circulating water pumps of the centrifugal type are provided for supplying cooling water to the oil coolers, hydrogen coolers, house alternator air cooler and other auxiliary services.

Two full-duty condenser extraction pumps are provided, each being capable of handling the

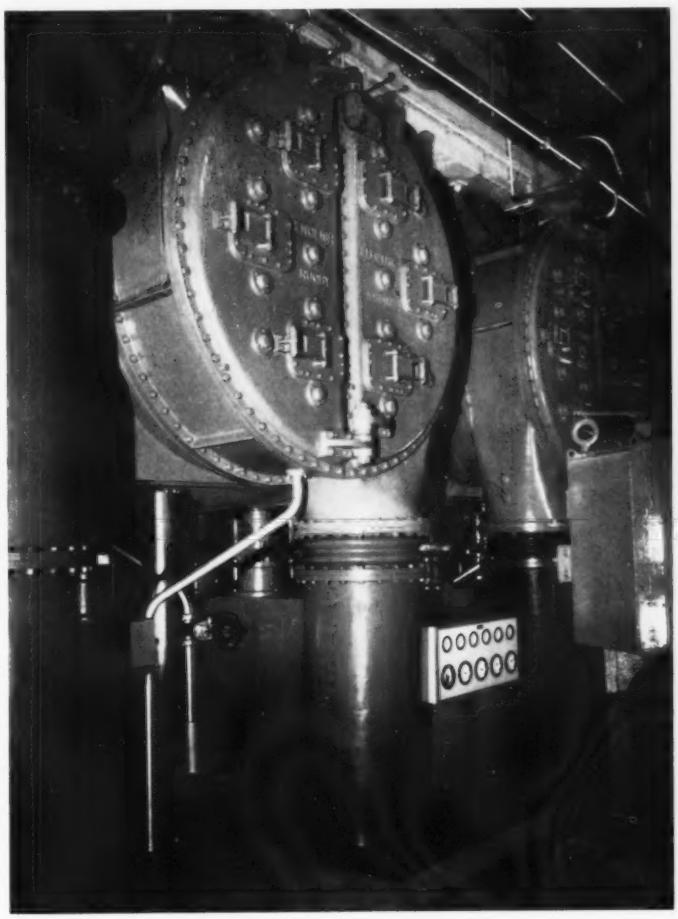


Fig. 8. A close view of the twin shell condensing plant from the basement, showing main water connections and part of one of the main circulating water pumps

condensate from the condenser at all loads under normal working conditions.

Air Ejectors

Three independent sets of two-stage steam jet air ejectors are provided. Two sets are each capable of 60 per cent. duty, and one set of 40 per cent. duty ; thus any two sets working together are capable of dealing continuously with the whole of the air entrained with the steam, and of maintaining the designed vacuum in the main condenser at full load.

A quick starting air ejector is also provided for rapidly evacuating the system when starting.

Feed Heater Automatic Protective Devices

The bled steam line to each high pressure heater is provided with a motor-operated isolating valve and a forced closing non-return valve. On the feed water side, each heater is fitted with motor-operated inlet and outlet and by-pass valves, and arrangements are provided for automatically isolating a heater on the steam side and for by-passing the feed water side in the event of the heater body flooding due to a burst tube or blocked drain pipe.

These arrangements consist of a float-operated switch fitted to each heater which, when tripped due to rising water level in the heater, causes (*a*) the bled steam non-return valve to be immediately closed, (*b*) the bled steam motor-operated isolating valve to close, (*c*) the motor-operated feed by-pass valve to open, and (*d*) the motor-operated feed inlet and outlet valves to close. Electrical interlocks are arranged on the feed valves which ensure that the motor-operated feed by-pass valve

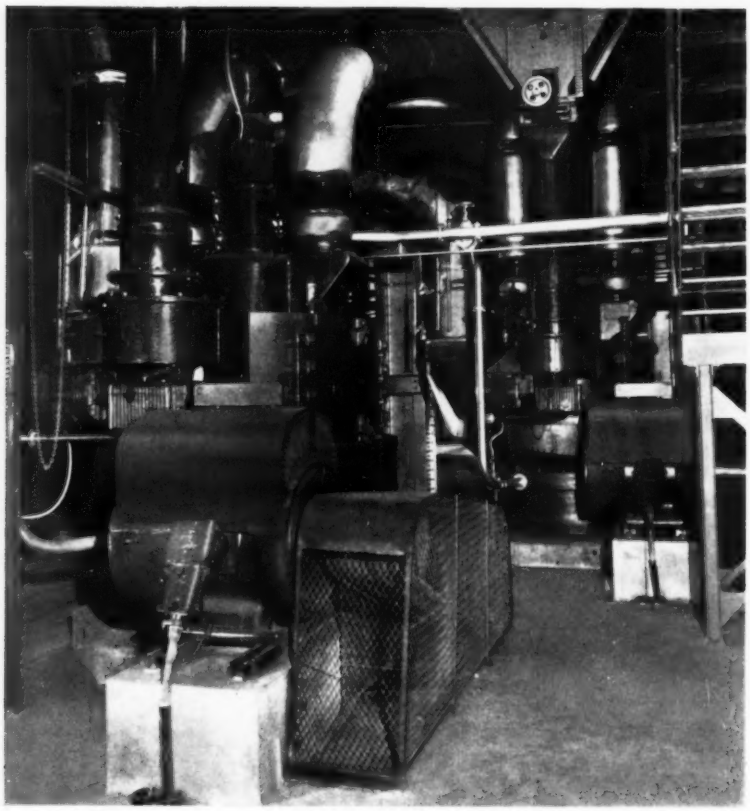


Fig. 9.

Showing the pulverising units with the closed-air-circuit type motor in the foreground

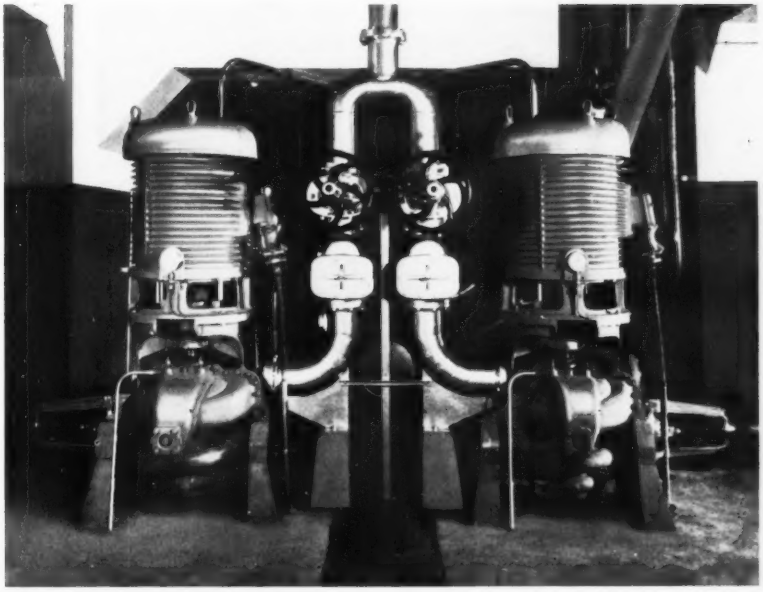


Fig. 10. *Duplicate main condensate extraction pumps and condensate discharge main*

is half open before the feed inlet and outlet valves commence to close.

Each float switch is provided with contacts which are wired to audible and visual alarms to give warning that the float switch has tripped.

Should the load on the turbine be suddenly removed, the operation of the governor anticipator closes the bled steam non-return valves and motor-operated isolating valves in the steam pipes to the three high pressure heaters. This prevents stored steam in the feed heaters and pipework from flowing back to the turbine and causing the machine to overspeed unduly. The bled steam non-return and isolating valves are also closed by the operation of the turbine emergency trip gear.

The bled steam lines to the two D.C. heaters are each fitted with automatic forced closing non-return valves operated by hydraulic pressure from float chambers on the heater bodies, so that if the heater body floods due to failure of the heater pump, the heater is automatically isolated from the turbine.

High and low level water alarms are arranged on the main condenser, the D.C. heaters and the evaporators. The alarms are wired to the central alarm panel on the unit control board.

BOILER HOUSE AND OTHER AUXILIARY DRIVES

A large number of squirrel-cage motors are employed for driving auxiliaries associated with the turbine, condenser and boiler.

As is usual for power station duty, the motors are all of the totally-enclosed type, the larger sizes having a closed air circuit with integral air to air heat exchangers as shown in Fig. 9. This illustration shows two motors driving the coal mills.

The smaller sizes are totally-enclosed fan-cooled, with ribs on the carcase to increase the surface area and so assist in heat dissipation. Fig. 10 shows two motors of this type, vertically mounted, driving condensate extraction pumps.

The motors are started by switching direct on line, special attention being paid in the design to the problem of reducing the starting currents to acceptable values. The motors will operate satisfactorily during voltage disturbances under emergency conditions which may result in the voltage applied to the terminals being reduced to 75 per cent. of normal.

Where variable speed is required, magnetic slip couplings are employed in combination with squirrel-cage motors. This system provides a

variable speed drive which is mechanically robust and requires a minimum of maintenance due to the absence of special cooling arrangements and commutators.

The two circulating water pumps are driven by squirrel-cage motors with magnetic slip couplings, both arranged vertically, as shown in Fig. 11. Each motor is rated at 315 h.p., 750 r.p.m., and the pump can be run at any speed down to 424 r.p.m. The magnetic couplings are protected by perforated metal screens. A water-cooled thrust bearing in the motor carries the weight of the motor rotor and the magnetic slip coupling. The speed is varied by means of a motor-operated regulator in the excitation circuit of each coupling, and the regulators are remotely-operated from control switches on the unit control board.

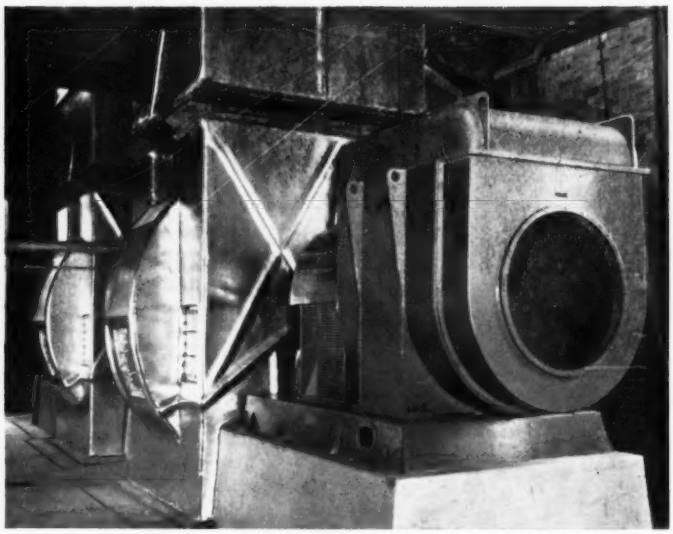


Fig. 12. *Induced draught fans, showing motor with magnetic coupling*

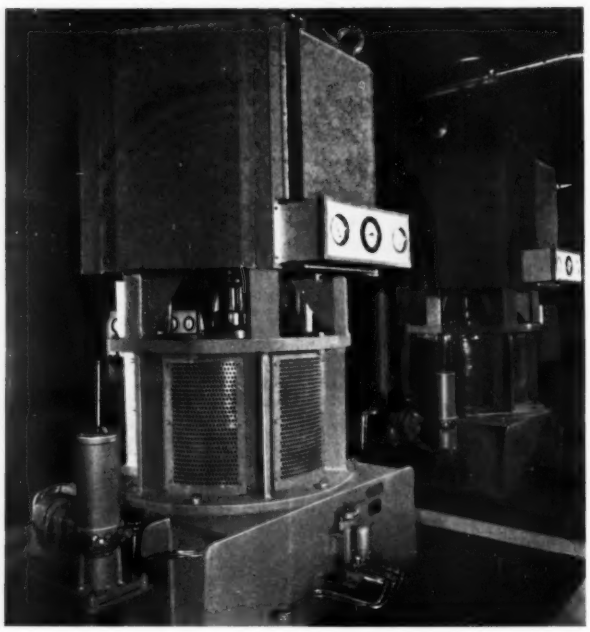


Fig. 11. *The two main vertical spindle circulating water pumps with the condensing plant in the background. The magnetic couplings on the pumps are enclosed by perforated metal screens*

The induced draught and forced draught fans are driven by squirrel-cage motors arranged horizontally with magnetic slip couplings overhung on the motor shafts. Each magnetic coupling has a flange-mounted flexible coupling connecting its output member to the fan, this arrangement being most economical in space. Fig. 12 shows a motor and magnetic coupling with drip-proof canopy and metal guard, driving one of the induced draught fans.

The forced draught fan motors are rated at 199 h.p., and fan speed is variable between 940 and 620 r.p.m., whilst the induced draught fan motors are rated at 524 h.p., and fan speed is variable between 730 and 300 r.p.m. The speed of the fans is varied automatically by means of regulators in the excitation circuits of the magnetic couplings, these regulators being operated by the automatic boiler control system. Rapid, smooth, and consistent response is obtained with any change in conditions.

THE MAIN ALTERNATOR

The main alternator, which is hydrogen cooled, generates at 11.8 kV and is solidly connected to a transformer stepping up to 66 kV, all switching being carried out at this voltage. The rated output of 55.5 MW is obtained on the high voltage side of the transformer at 0.8 power factor which is equivalent to approximately 0.74 power factor at the machine terminals. Directly driven from the main alternator through a flexible coupling is a 4.5 MW air cooled house service alternator (described later), which generates at 3.3 kV. Excitation for both alternators is supplied from a separate motor-driven exciter set.

The principles involved in the cooling of rotating electrical machines by means of hydrogen are well-known and it is unnecessary to deal with them in detail although it may be of interest briefly to summarise the main advantages to be gained from the use of this gas as the cooling medium. These are :—

(1) Improved efficiency due to the reduction of the windage and ventilation losses on account of the very low density of hydrogen, which is about one-fourteenth that of air.
(2) Greater output per unit weight of active material (the iron and copper in the stator and rotor) and reduced temperature gradients due to the superior thermal properties of hydrogen compared with air.
(3) The virtual elimination of the deterioration of the insulation due to corona.
(4) The absence of the fire risk because hydrogen will not support combustion.
(5) A reduction in windage noise due to the low density of the gas.
(6) Greater cleanliness due to exclusion of dirt by the complete sealing of the machine.

The main features of interest are associated with the means of preventing the escape of hydrogen along the shaft where it passes through the end brackets, and with the methods of controlling the admission of the gas. However, before describing these, there are several points in the construction of the alternator itself which are unusual.

The stator is of the two-unit construction. The outer frame is fabricated from rolled steel plate and cast steel end rings, and forms in effect a gas-tight housing with openings for the hydrogen coolers.

As is well-known, mixtures of hydrogen and air are explosive over a range of approximately 5 per cent. to 70 per cent. of hydrogen by volume. In order to obtain the maximum benefit from this method of cooling, the concentration of hydrogen in the machine should obviously be maintained as high as possible, normally 95 to 97 per cent., with the result that there is a wide margin of safety above the explosive limit. However, in order to guard against the risk of an explosion should the purity of the gas be allowed to fall so low as to come within the danger zone due to failure to follow the simple operating procedure, the outer frame is designed to be explosion safe.

The inner frame is also fabricated from rolled steel plate and is in the form of a skeleton structure into which the stator core and windings are built in the conventional way.

The two units were transported to site separately, thus reducing the maximum weight to be handled. The outer frame is fitted with a hardened steel key on which the inner frame slides while being drawn into position by means of the crane. Fig. 13 shows the initial stage of this threading operation when the alternator was in course of erection for testing at Stafford Works. The whole operation was completed in a few hours.

During running the electro-magnetic attraction between the rotor and the stator is, of course, not uniform and reaches its maximum along the axis of the rotor poles with the result that there is a distorting force acting on the stator and revolving at synchronous speed. In order to prevent the transmission of any vibration at double the generating frequency, arising from this cause, to the outer frame and thence to the bearings and foundations, the inner frame is mounted flexibly within the outer. The weight is carried on a number of of studs fixed at one end to the inner frame and at the other to the outer frame. These provide the necessary flexibility in the mounting between the two frames. The torque is taken on a number of tangential members.

The main alternator is entirely self-contained in that the gas coolers are housed in the outer frame and the gas is circulated by means of axial flow fans, having blades of aerofoil section, mounted

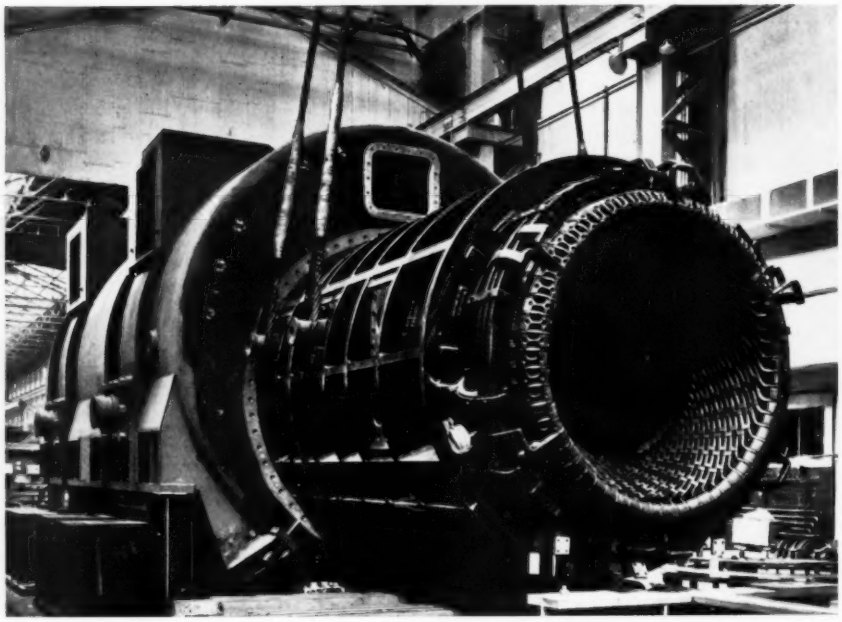


Fig. 13.
Threading the inner stator into the outer casing of the 55.5 *MW hydrogen cooled turbo-alternator for Stourport Power Station, at The English Electric Company's Stafford Works*

on the rotor. This construction eliminates all external ducting, and thus greatly facilitates the attainment of a gas-tight enclosure.

As will be seen from Fig. 14 there are two coolers mounted at right-angles to the axis of the machine in the upper part of the frame. At the end to which the water connections are made, the tube plate is bolted solidly to the frame wing while the return end is free to expand or contract in relation to the frame with temperature changes. Each cooler is designed with divided water boxes so that half a cooler may be shut off at a time for tube cleaning while the unit remains in service on slightly reduced load.

The rotor is of conventional design and is coupled to the turbine through a multi-tooth flexible coupling. It is machined from a single forging of carbon steel having small additions of nickel and vanadium. The usual ventilation channels are provided beneath the winding slots and down the centres of the teeth. As the result of cutting the slots to contain the field winding, the inertia of the rotor is different across the two major axes, so that the static deflection at the centre of a long rotor such as this is appreciably greater when the pole axis is horizontal than when it is vertical. This effect gives rise to a vibration of the rotor at twice the running frequency, and in order to eliminate this as far as possible transverse grooves are machined in the pole centres.

The field winding is formed from semi-hard silver-bearing copper in order to prevent coil distortion through differential thermal expansion. The turns are taped throughout their length with glass-backed mica tape which completely eliminates the risk of short circuits developing between turns due to leakage across the edges of strip separators.

The leads from the winding are brought out of the gas-tight housing by means of semi-circular conductors running in the central inspection hole of the forging to sliprings which are totally enclosed and ventilated from the house alternator air circuit.

The bearings which are of the usual spherically seated type are carried in cast steel brackets which are bolted to the outer frame.

Shaft Seals

The shaft gas seals are of the floating ring type, the principle of which is shown in Fig. 15. Two bronze rings are mounted side by side in an

annular groove in a cast steel support which is carried rigidly from the inner surface of the bearing bracket. They are permitted to move with the shaft in a plane perpendicular to the axis of the rotor, but are prevented from rotating with it. The clearance between the rings and the shaft is kept down to the minimum consistent with satisfactory running. Similarly, the clearance between the rings and the side of the groove in which they are contained is kept small to reduce the oil flow as much as possible and to maintain a satisfactory seal at this point. The groove behind the rings is supplied with oil at a pressure of about 10 lb/sq. in. above that of the gas in the frame, and feed holes in the rings allow the oil to pass into a small annulus formed between the rings by machining the rings themselves. The film of oil thus maintained between the rings and the shaft forms the gas seal and at the same time lubricates and cools the rings.

The seals are supplied with oil which is normally vacuum treated to remove entrained air and water in order to prevent adulteration of the hydrogen occurring from the oil which flows to the gas side

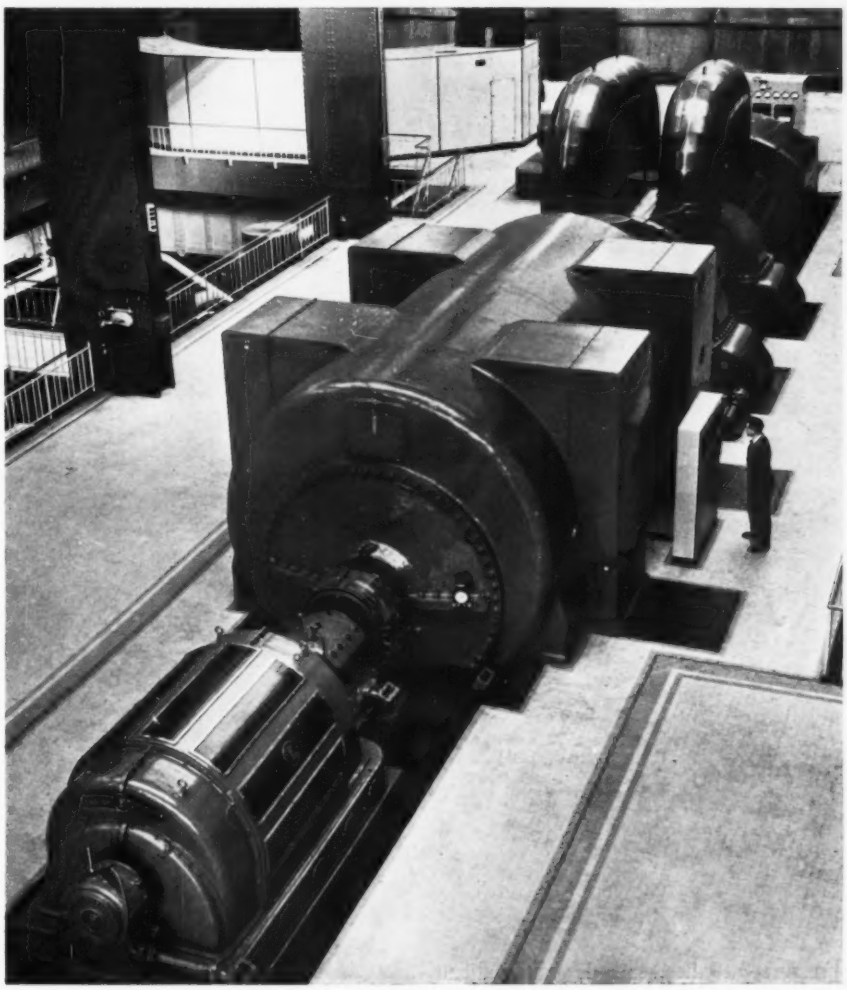


Fig. 14.

The complete turbo-alternator set from the alternator end

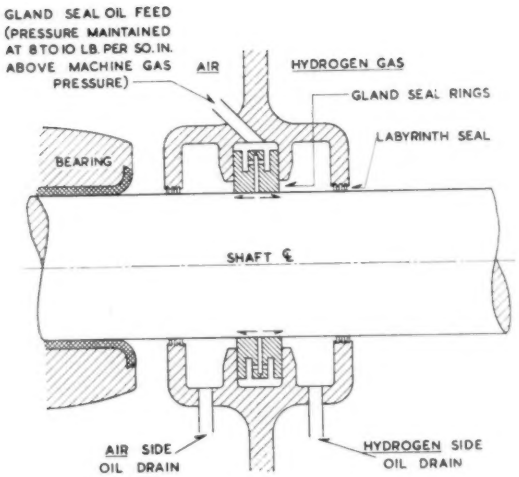


Fig. 15. *Principle of the floating ring type liquid shaft gland seal*

of the seals. A seal oil treating unit, shown in Fig. 16, which is located at basement floor level within the foundation block, contains the various items of auxiliary equipment associated with the oil supply to the seals.

This unit consists of a welded steel cylinder divided into two sections, one of which is an oil reservoir and the other a vacuum tank, together with two oil pumps, a vacuum pump, a pressure control valve, and a number of automatic devices and alarms. The seal system uses turbine lubricating oil, a make-up or discharge connection being made to the main bearing drain so that the quantity of oil in the reservoir is automatically kept constant although some small interchange between the bearing and seal system may take place by creepage along the shaft between the bearings and the air side of the seals.

Fig. 17 shows the seal oil system in diagrammatic form. Normally oil is fed to the seals by the main pump "A," which is driven by an A.C. motor. The pressure at the seals is automatically maintained at about 10 lb/sq. in. above the hydrogen pressure in the frame, whatever it may be, by means of a differential pressure regulator "B" responsive to gas and oil pressures. Control of the pressure is effected by varying the proportion of the pump output which is by-passed to the vacuum tank "C," or to the reservoir "D" if the oil is not being vacuum treated.

After leaving the pump the oil is passed through a cooler "E" and thence through self-cleaning filters "F" to the seals. Oil draining from the hydrogen side of the shaft seals is taken to de-foaming tanks "G" located under the outer frame where it is allowed to settle, the hydrogen which comes out of the foam being returned to the frame. One de-foaming tank is provided for each seal to avoid the possibility of oil vapour being circulated through the machine due to any slight difference between the characteristics of the two rotor fans. The level of oil in the de-foaming tanks is maintained by a float

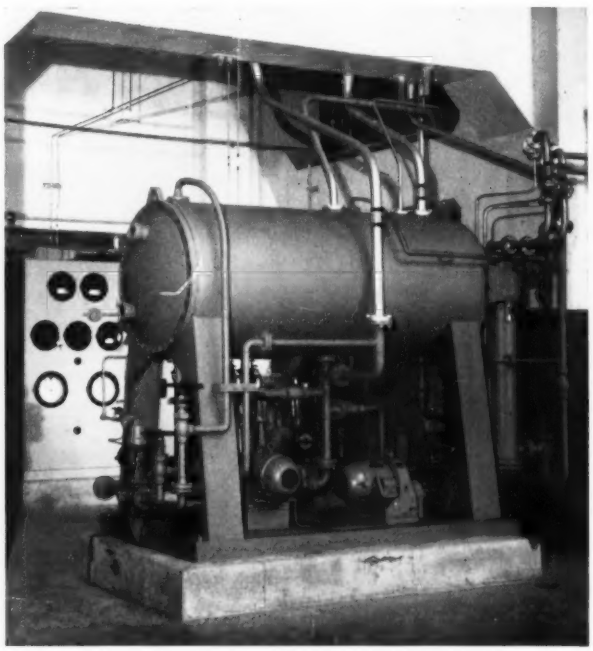


Fig. 16. *The hydrogen shaft gland seal oil treatment unit with the control panel in the background*

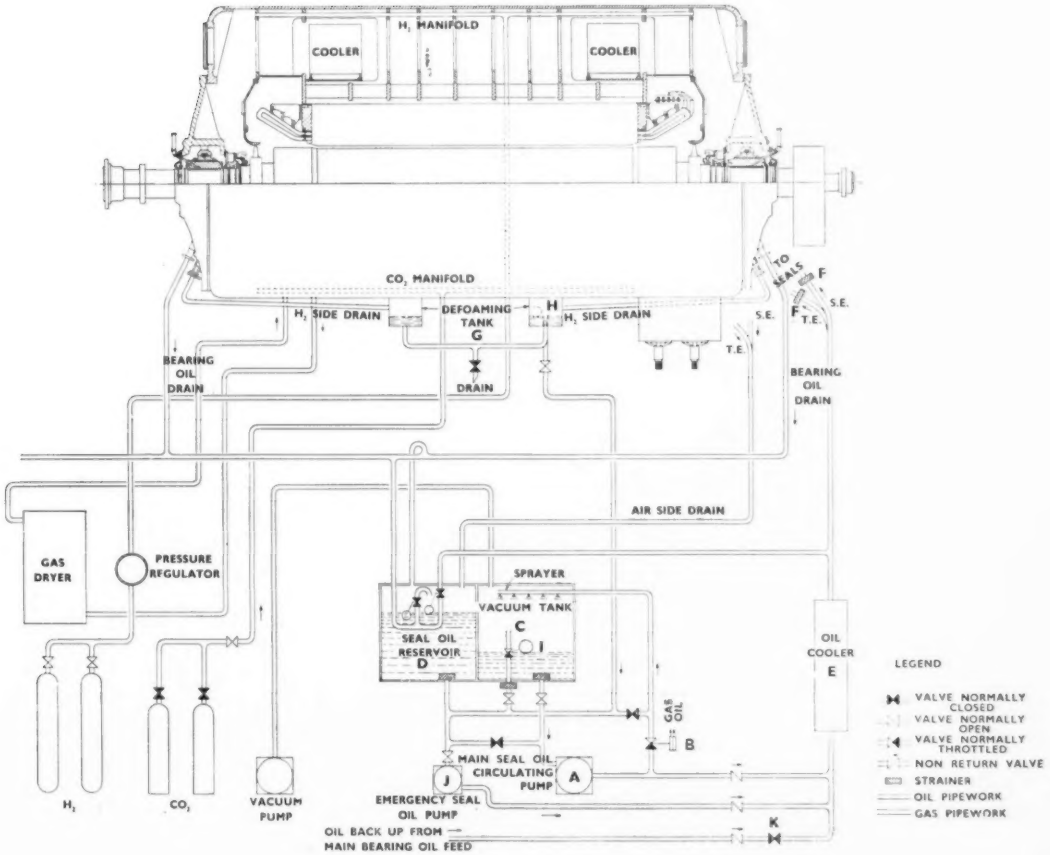


Fig. 17. The hydrogen seal oil system in diagrammatic form

valve " H," which ensures that under all conditions of oil flow a gas seal is provided at this point.

The oil from the de-foaming tanks is taken directly to the vacuum tank " C " through a float valve " I," while that from the air side of the seals is drained into the top of the reservoir tank " D." Oil from the bottom of the reservoir then enters the vacuum tank "C" with the gas-side oil from the de-foaming tanks. This method ensures that the oil in the reservoir is kept in circulation.

Provision is made for by-passing the vacuum tank for maintenance purposes without taking the unit out of service. In this case the pump draws directly from the seal oil reservoir, and the gas-side as well as the air-side seal oil is returned to the reservoir. Operation in this way can be continuous but the consumption of hydrogen will be increased because of the necessity of admitting more gas to compensate for the infiltration of air through the medium of the untreated oil.

If the pressure of the oil at the alternator seals should drop due, for example, to the failure of the main pump, differential pressure switches responsive to both gas and oil pressures bring in the standby oil pump " J." This pump is driven by a D.C. motor deriving its supply from the station battery. The oil pressure it provides is determined

by a relief valve. This is preset to give a pressure at the alternator seals of 10 lb/sq. in. above the maximum hydrogen pressure at which the set will be operated. As a precaution against the failure of both motor-driven pumps, a back-up oil supply for the seals is taken directly from the main bearing supply of the set through the valve " K."

In order to prevent any possibility of pockets of hydrogen collecting anywhere in the lubrication system of the set, a vapour extractor is provided on the main oil tank to maintain a slight degree of vacuum above the oil and thus ventilate the oil pipes and tanks.

Gas System

Before hydrogen can be safely admitted to an alternator the oxygen contained in the frame must be reduced to a concentration which will not give a mixture within the explosive range at any time during the filling operation. Two methods of doing this are employed. In the first, and commonest, carbon-dioxide is used to displace the air, and in the second, the frame is partially evacuated before hydrogen is admitted. The former method is used in this installation.

As will be seen from Fig. 17, two perforated gas distribution pipes are welded into the outer frame, one at the top and the other at the bottom. These pipes can be connected by means of a suitable arrangement of valves either to the gas supply manifolds located within the foundation block at basement level or to atmosphere. Prior to filling the frame with hydrogen the air is displaced by carbon-dioxide until the oxygen content is sufficiently reduced. During this operation the distribution pipe at the top of the frame is connected to atmosphere while the carbon-dioxide is let in through the lower pipe. In this way the least possible mixing of air and carbon-dioxide takes place so that the minimum quantity of gas is used. After the necessary concentration of carbon-dioxide has been built up in the frame, the lower distribution pipe is connected to atmosphere while hydrogen is admitted through the upper one. In removing hydrogen from the frame, the reverse procedure is, of course, followed. Filling and emptying can be carried out with the set stationary or running, but in the latter case more gas is used because there is complete mixing of the frame contents.

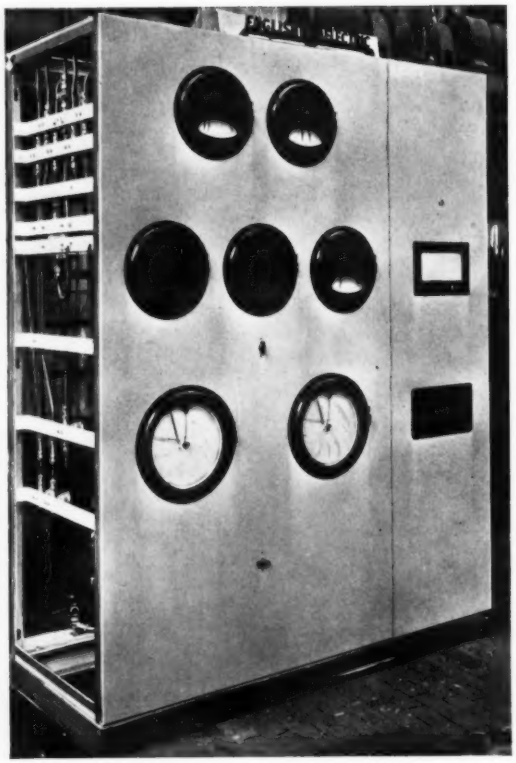


Fig. 18. *Front view of hydrogen control cubicle at Stourport Power Station*

The carbon-dioxide is obtained from commercial cylinders four of which are connected to a manifold equipped with non-return valves in the feed pipes enabling the cylinders to be replaced as they become empty. Control of the rate of discharge is effected on the cylinder valves.

Hydrogen is also obtained from standard cylinders with a capacity of 165 cu. ft. of free gas compressed to approximately 2,000 lb/sq. in. Six of these cylinders are connected in two banks of three to a manifold, one bank being in use at a time. Control of the hydrogen is by either of two two-stage pressure reducing regulators. One of these is preset to maintain the hydrogen pressure in the frame at the designed value of $\frac{1}{2}$ lb/sq. in. gauge. The second regulator can be manually adjusted to maintain any pressure up to 15 lb/sq. in. gauge, which is the maximum operating pressure for which the unit is designed. Full load of the

alternator is obtained with a hydrogen pressure of ½ lb/sq. in. gauge, but it is capable of giving an additional 1 per cent. in output for every 1 lb/ sq. in. increase in gas pressure up to the maximum of 15 lb/sq. in. gauge.

Supervision of the gas conditions prevailing in the alternator is obtained from instruments mounted in the hydrogen control cubicle seen in Fig. 18. The two instruments in the top row are pressure gauges, with alarm contacts, measuring the hydrogen pressure in the frame. One is scaled 0-2 lb/sq. in. for use under normal conditions, and the other 0-20 lb/sq. in. to cover operation at higher gas pressures. In the second row are the gas purity indicator, the differential pressure gauge, measuring the pressure set up by the alternator fans as a check on the purity indicator when the set is running at normal speed, and a vacuum gauge in connection with the vacuum treating process of the seal oil referred to earlier. The bottom row of instruments consists of recorders for the gas purity and gas pressure. The right-hand section of the control cubicle houses the alarm system associated with the oil and gas supplies. This operates a master alarm on the control desk at the turbine gauge board, the particular alarm given being indicated by a flashing signal on the cubicle.

The method of measuring the purity of the gas in the alternator may be of general interest. It is extremely simple and consists of making a direct measurement of the density of the frame contents. Sampling lines are taken from the alternator to a small motor-driven blower housed in the control cubicle. This blower runs at constant speed and sets up a pressure proportional to the density of the medium passing through it. The pressure is measured by a floating bell type differential gauge scaled 0-150 per cent. A calibration valve is provided to enable the instrument to be adjusted so that with air in the frame a reading of 100 per cent. is obtained. This is taken as the reference and can be checked at any time with the set in service by connecting the blower to atmosphere. Correction curves are provided to cover variations in gas pressure.

A small silica-gel gas dryer is provided and connected across one of the alternator fans. This serves to keep down the humidity of the gas in the frame if it should tend to increase when the seal oil is not being vacuum treated. Water detectors are fitted and connected to the low points in the frame to give warning of the presence of free water which can then be drained off.

HOUSE SERVICE ALTERNATOR AND EXCITERS

The house service alternator is of conventional design and is ventilated on the closed circuit principle with air circulated by fans on the rotor. In order to prevent an excessive drop in voltage when motors taking a starting kVA input large in relation to the alternator rating are switched on to it, the short circuit ratio is considerably higher than is usual for machines for normal duties.

Excitation for both alternators is provided by one or other of two exciter sets, one of which is a standby. Each consists of a main exciter for each alternator and a common pilot exciter, driven by a squirrel-cage induction motor at 1,000 r.p.m. synchronous. These exciter units are installed in a separate room opening off the turbine operating floor.

Automatic voltage regulators of Brown Boveri manufacture are provided for controlling the excitation to the main and house service alternators.

75,000 kVA TRANSFORMER

The main alternator is solidly coupled to a 75,000 kVA transformer which steps up the voltage from 11.8 to 71.7 kV at no load. The transformer is of the OFW type in which the oil is circulated by a pump through a separate cooler employing water as the cooling agent. Since OFW type transformers have a negligible natural cooling surface, failure of the water cooling system would shut down the transformer, and so duplicate coolers are provided, each of full load cooling capacity.

The transformer windings are connected in star on the H.V. side and delta on the L.V. side, the connections being brought out through porcelain bushings mounted in the tank cover.

STATION SWITCHGEAR

The switchgear at this station is entirely indoor design, and is accommodated principally in a

four-storey building adjacent to the main control room. A general view of the switchgear room is shown in Fig. 19.

The 66 kV switchgear consists of six type OBL7c air-blast circuit-breakers having a certified short-circuit rating of 1,500 MVA, and a normal full load current rating of 800 amps. An arc suppression coil is utilised to earth the neutral of this 66 kV system. The circuit-breakers and associated local control cabinets are accommodated in wire mesh enclosures on the first floor of the switch house.

The air compressors and main storage receivers comprise two self-contained units, one driven by a 10 h.p. A.C. motor and the other by a D.C. motor. The compressor unit employed is of the 3-stage air cooled type, fitted with relief valves between stages, and automatic unloading gear, inter-cooling coils being fitted between high and low pressure cylinders.

Air pressure relays are so set that on automatic control the compressor motors will be started at a main receiver pressure of 450 lb/sq. in. and switched off at 500 lb/sq. in.

An alarm relay switch is fitted whereby a warning is given on the main control board at a pre-set pressure between 400 and 450 lb/sq. in. The air connections are such that the compressor may charge either or both receivers. Duplicate bus-pipe air lines are incorporated in all compressor and circuit-breaker equipments.

The 66 kV circuit-breakers are mounted on twin local air receivers, having a capacity sufficient for two complete make-break operations. Each singlephase consists of three porcelain bushings, two of which, bridged by an air-tight chamber containing two interrupting contacts, are mounted on the twin receivers, whilst the third carries the series make switch blade. The three single-phase sections are coupled electro-pneumatically, forming a complete three-phase unit.

In the rupturing operation, the air blast effectively separates the interrupter and extinguishes the arc, but since the optimum gap is insufficient to isolate the circuit when the blast has ceased, a second set of contacts, namely those of the make switch, are arranged to open after arc extinction but before blast cessation.

On completion of this opening operation, the interrupting contacts close again under spring impulse. When it is required to close the breaker, air is admitted to the back of the make switch piston which causes the switch arm to close, impelled on the latter part of its stroke by a strong spring.

The control of the air for such operations is by

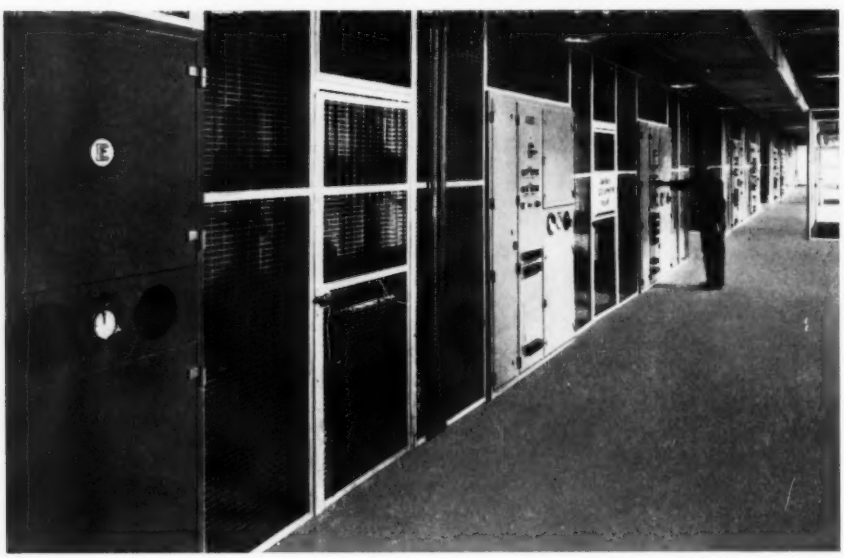


Fig. 19.
View of the switchgear room, showing circuit-breakers in enclosures

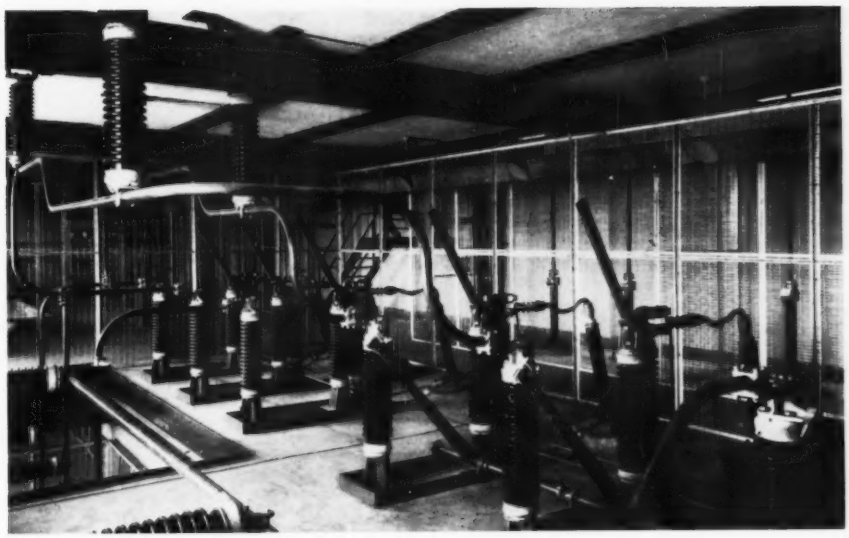


Fig. 20.
66 kV pneumatically operated isolating switches

electro-pneumatic valves, the functioning of which can be initiated from either a remote point, manually, or automatically through the existing protective scheme. Push button switches for maintenance or emergency operations of the breakers are also fitted in each local control cabinet.

Connections to other floors are made by condenser type through bushings on which current transformers, where required, are mounted, the bushing stalk being utilised as the primary winding.

The voltage transformers of which there are two, are of the oil-immersed type, 66 kV/110 V, with double secondary windings. Conservator vessels are provided together with silica-gel breathers and Buchholz alarm and trip devices.

The cubicle type 66 kV control board provides for the remote operation of the circuit-breakers and comprises eight panels each with mimic diagram, electrically operated semaphores, control switches, relays, indicating lamps, etc. Separate pedestals are employed for the synchronising equipment.

Safety interlocks of the "Castell" type are provided whereby access to any live metal of the 66 kV gear is impossible until all switches and isolators have been locked "open." The interlocking device is so arranged that each individual unit of an associated group is rendered innocuous in the correct order.

Triple pole isolating switches (Fig. 20) employed in the 66 kV system are of the rotating post vertical break type. Pneumatic operation is provided and they are operated from the local control cabinet of the associated circuit-breaker. Manual control is also provided for maintenance or emergency purposes.

The main and auxiliary busbars are situated in the two storeys above the circuit-breakers.

3.3 kV is used for auxiliaries, the neutral of this system being earthed through a voltage transformer. The 3.3 kV switchgear comprises 26 truck type units with OB-33 solenoid operated air-break circuit-breakers having a certified short-circuit rating of 150 MVA at 3.3 kV and current ratings up to 1,200 amps.

Acknowledgments

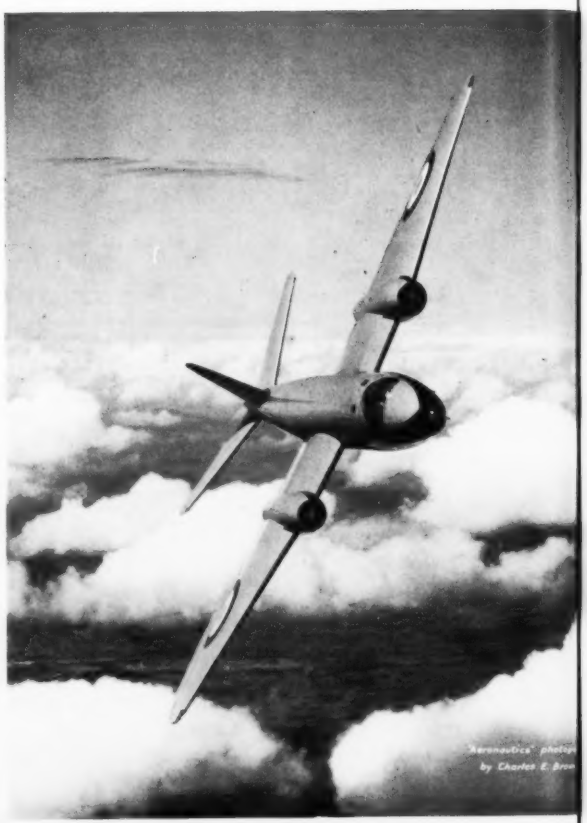
Contributions to this article were made by Mr. W. E. Streete, A.R.Ae.S., Assoc. I.E.E., Manager, Plant Sales Section; Mr. C. Shute, A.M.I.E.E., Transformer Sales Department; and Mr. J. F. Smith, Switchgear Sales Section; describing respectively the boiler house and other auxiliary drives, the 75,000 kVA transformer, and the station switchgear.

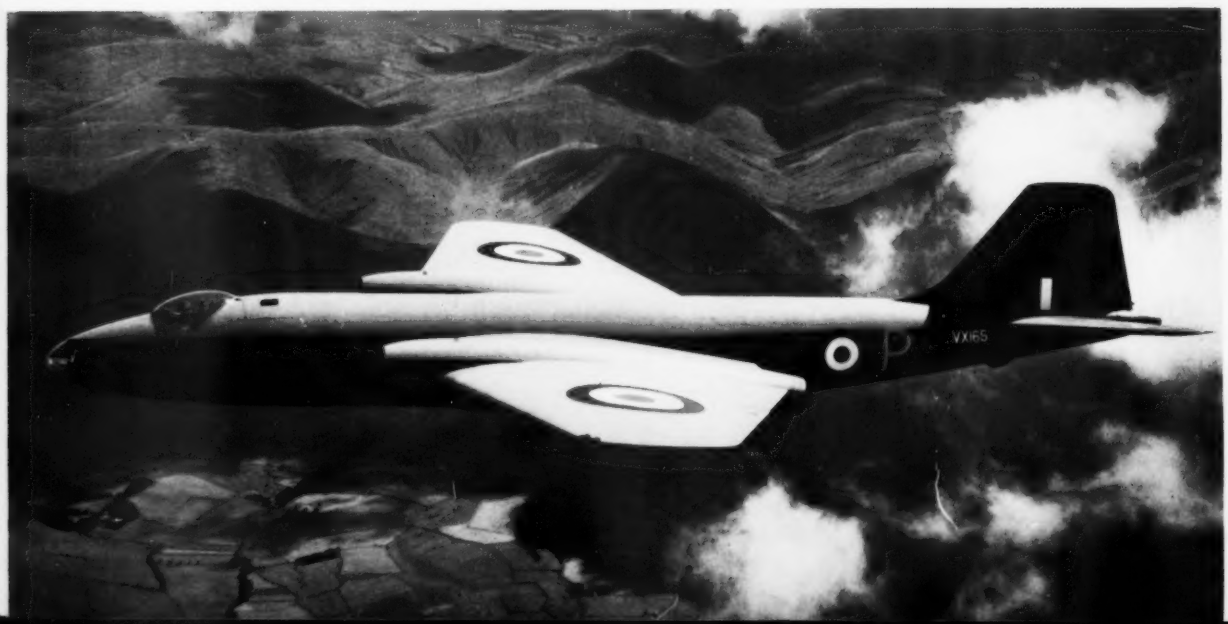
The Canberra Jet Bomber

The 'ENGLISH ELECTRIC' Canberra jet bomber is now in production as part of Britain's rearmanent programme.

The Canberra is Britain's first jet bomber and the accompanying illustrations show the Mk. 2, which is the tactical version for the Royal Air Force. It is a twin-engined mid-wing monoplane powered by Rolls Royce 'Avon' axial-flow jet turbines. It carries a crew of three in a pressurised cabin and is fitted with a transparent nose and visual sighting panel for the use of the bomb aimer. The wing span is 64 ft., the length 65 ft. 6 in., the height 15 ft. 7 in., and the aspect ratio 4.3. While no details of performance can be disclosed, extensive flight tests have confirmed that the Canberra has exceptional performance at both low and very high altitudes. The development of this aircraft has been facilitated by the excellent research plant at the Company's Warton aerodrome.

In addition to manufacture by The English Electric Company, production orders have been given to three other aircraft constructors in Great Britain, namely, A. V. Roe Ltd., Handley Page Ltd., and Short Brothers & Harland Ltd., who will work as "daughter" firms to this Company. The Canberra is also to be built in Australia and in all probability will be manufactured in the United States of America.





Photograph by Charles E. Brown

By Courtesy of Flight

Hot Strip Mill Flying Shear at John Summers & Sons Ltd., Shotton

By A. ASBURY, B.Sc., A.M.I.E.E., Assistant Chief, Special Engineering Section.

PARTICULARS OF EQUIPMENT in the hot strip mill of John Summers & Sons Ltd., in their factory at Shotton, were given in the previous issue of the journal. Details of the flying shear were omitted as it was felt that owing to its special interest, and the modernisation of the drive, it would be possible to deal more fully with both the new and old schemes in a separate article.

The Shearing Problem

A considerable proportion of the output of the hot strip mill is required in the form of plates of thicknesses over $\frac{1}{8}$ in. This material is roller straightened and levelled, then trimmed to size to give the final product of prime plate. Each piece will yield up to 200 feet of plate and it is clearly undesirable to coil this material. It follows that some means is required to cut the strip as it leaves the mill, into lengths which can be handled in the subsequent processes.

The strip is cut into lengths which can be dealt with in the trim, level and shear line, and which will vary from 12 ft. to 22 ft. according to the finished size of plate. This strip may be finished in the hot strip mill at any speed between 800 and 1,450 ft. per minute, and it is necessary for the shear to give consistent cut lengths over this range of operation.

In order to obtain this range of cut lengths, the ratio $\frac{\text{strip speed}}{\text{peripheral knife drum speed}}$ is varied and will usually have values from unity to two. It is possible to make a cut with the knives running faster than the strip because the time of shearing is very short. Fig. 1 shows the shear in action, with cut edge on left. The upper drum is at one of the "no-cut" positions about 40% through the cutting cycle.

In addition, it is necessary to crop the front and rear ends of material to be coiled so as to facilitate the operation of feeding the coils into the pickling lines.

The Flying Shear Equipment Installed 1939

At this time the disadvantages of the hydraulic system and gear systems in general were being discovered and it was decided that this shear should be supplied by a Ward Leonard equipment. It was realised that much of the difficulty experienced was due to the shock nature of the load, and consequently any system developed for controlling the shear must be able to withstand the shearing peaks. At the same time it should give means of determining the cut length and maintaining it within tolerable accuracy.

This was achieved by driving one selsyn transmitter directly from the motor of No. 8 stand and another through a variable ratio gear from the shear motors. The revolutions of the two transmitters were compared in a differential selsyn mounted in the operation desk. When the rotor of the differential selsyn was stationary, the ratio of shear motor speed and Stand 8 speed was dependent on the setting of the variable ratio gear. Indication of the ratio setting of the latter gave a means of determining the cut length, and the calibration of the ratio mechanism was in feet and inches.

The mode of operation therefore was to set the variable ratio gear to the value required for the cut length desired, and to use manual adjustment of a vernier rheostat in the generator field circuit to obtain matching of the speeds on the differential selsyn.

This system worked very well and gave the best results obtainable on a flying shear at that time.

Fig. 1.
The flying shear at John Summers & Sons Ltd.

It was found, however, that the indication obtained from the variable speed gear became progressively less accurate. In addition it was difficult for the operator to maintain good accuracy throughout an eight hour shift, and accordingly it was necessary to allow 8 in. extra on the plate length to provide for trimming and possible short plates. The adjustment by the operator was also very dependent on whether or not it was necessary to make some change in the speed or the screwdown setting of No. 8 stand. If this happened to occur during a piece, even greater errors in length might occur. It was also difficult to allow for the effect of different roll diameters in Stand 8.

The cropping was carried out by accelerating the shear knives to a fixed maximum speed which was in excess of any strip speed used on the mill. To ensure the ability to carry out this rapid acceleration a rather special arrangement of exciters was used to ensure the necessary rapid changes of the shear generator voltage. Both deceleration after a front crop and acceleration before a rear crop must take place while the strip is passing between the knife drums. The angular travel available for these changes is therefore limited to about $\frac{7}{8}$ of a complete shearing cycle, and this angular travel must not be exceeded whatever the cutting speed of the knives.

It was realised that an improvement over the performance obtained with the manual control could probably be obtained, and accordingly The English Electric Company was asked to prepare an improved control system for the shear. Since it was out of the question to stop production on the mill, the additional equipment had to be so designed that it could be fitted during a shut-down period. Further, due to limitations of space and other considerations it was necessary to re-wire the existing contactor board. It was calculated that if the shear could be made to cut within $\pm$ 1 in. the cost of the additional equipment could very soon be recovered in the increased percentage of prime plate.

The original scheme had the possibility of initiation by load relays, but experience had shown that the variable shape of the end of the piece and the changes in rolling load were such as to make this means of initiation inaccurate.

It was necessary to have an operator to set the shear for cut length. Such an operator acquires the skill to allow for irregular ends and obtains an initial cut and crops which give the minimum

waste. It was therefore decided to make the revised equipment suitable for manual initiation only.

An analysis of the shearing operation was carried out. It was shown that the skill required of the operator could be greatly reduced if a special matched acceleration was used. With this type of acceleration the point in the mill chosen for initiation is independent of strip speed and varies only in a logical manner with the cut length. This means that over a wide range of conditions the operator can make a much better first try at cropping and is able to obtain very small waste in the crop prior to cutting a piece into plates.

Revised Scheme for Control

The accuracy required, i.e., 1 in. in 20 ft., corresponds to 0.4 per cent., and it was decided to aim at an accuracy of 0.2 per cent. It was felt that the maximum benefit could only be obtained in a control system which enabled the operator to set the desired cut length on a scale without any complex calculation or use of nomograms. This is due to the fact that the shearing orders may frequently be for one or two pieces only, and there is little time for the operator to do anything other than change the setting on his controls between successive pieces. Further, the facility of setting the cut length first time eliminates a great deal of waste.

Certain errors occurring in the shearing operation cannot be related to the electrical measuring system. These are extrusion effect in the last stand, the drop in speed during cutting and the effect of waviness in the strip between Stand 8 and the shear. To cover these errors which might reasonably be expected to remain constant for a given cutting duty it was decided to provide a vernier rheostat which would normally be set to take care of these errors.

In addition, the accuracy required is such that it is necessary to allow for the changing diameter of the rolls in No. 8 stand. This may be as much as 0.5 in. in 20 and accordingly the control was devised in such a way as to cover a still wider range of roll diameters and allow for present and possible future practice.

To maintain the high accuracy required the form of control must not be affected by the steelworks atmosphere. Accordingly, rather special rheostats were designed to give the precise resistance values needed and avoid changes in contact drop which

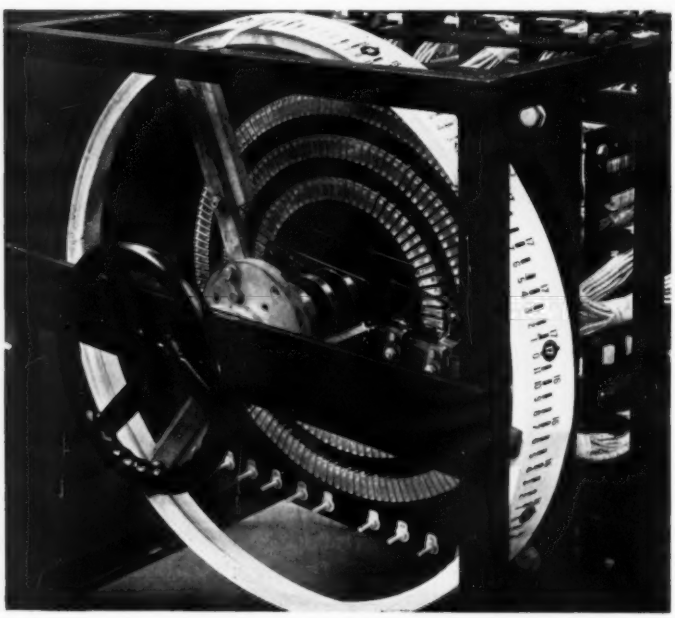


Fig. 2. The main cut length rheostat with its indicator

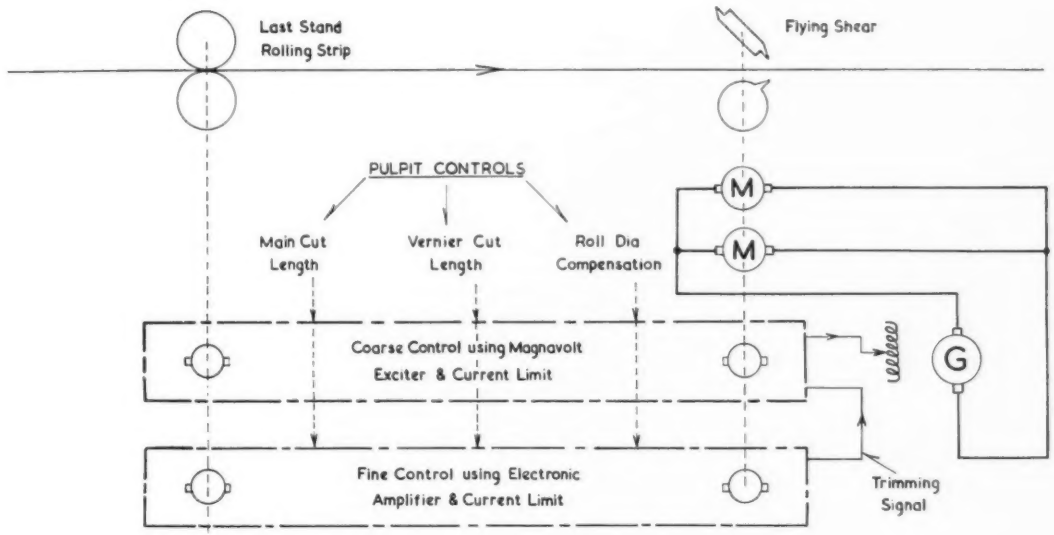


Fig. 3. Block diagram for the flying shear control scheme

might occur during the normal life of the equipment. One of these rheostats is shown in Fig. 2.

In order to obtain the high accuracy, it was decided to use a magnavolt* speed control with a superimposed electronic trimming. It was also arranged that in an emergency the magnavolt speed control would automatically take over and give safe, though less accurate, control. The magnavolt was arranged to supply the existing shear generator used for the earlier Ward Leonard equipment. The magnavolt speed control had its own tacho-generators which were arranged to give the maximum amplification but could not at the same time give complete independence of temperature change and hysteresis. The superimposed fine speed control was arranged to be free from these errors and fed the input of the electronic amplifier. The latter was arranged to correct the magnavolt speed control in such a way that the final speed depended almost entirely on the speed required to satisfy the electronic control. By this means the power required from the electronic control was kept to a minimum and the high accuracy was maintained.

It was mentioned that a special matched acceleration was required to ensure that the shear reached its correct cutting speed when the knives met. This requires an acceleration control which can override the speed control. This also has electronic trimming to obtain the best response and accuracy. Again the circuits were so arranged that the two regulating systems operated without interference. A block diagram in Fig. 3 shows the relation between the various parts of the control.

When the complete scheme was prepared it was evident that very small extra expenditure, together with adaptation of some of the original equipment, would enable the sensitive circuits for the electronic equipment to be used as indication for a manual control. This was accordingly incorporated so that the shear has in effect two stand-by modes of operation.

Results Obtained

Since the final commissioning in March 1950, the electronic equipment has been in continuous operation. Operators have found that it is possible to cut lengths of plate which are consistently within $\frac{1}{2}$ in. of the desired length, and when there is little disturbance in the mill setting the variation may be as little as $\pm \frac{1}{4}$ in. This applies over the whole range of operating conditions, i.e., 800 to 1,400 ft. per minute strip speed and 12 to 22 ft. cut length.

* English Electric design of two-stage rotary amplifier. See The English Electric Journal, March, 1950.

Electronic Control Applied to a Hot Strip Mill Flying Shear

By W. H. SYKES, A.M.I.E.E., Industrial Electronics Department.

THE PRECEDING ARTICLE in this issue outlined the control of the flying shear in the hot strip mill of John Summers & Sons Ltd. In the revised control, the electronic gear is used to increase the sensitivity of speed matching and so enables lengths of plate to be cut more accurately. This article describes the electronic gear and the methods adopted for applying it in steel mills.

Purpose of Electronic Gear

The first purpose of the electronic gear is to provide fine speed control, and the special properties of electronic circuits are most appropriate for this.

In the first place the accuracy required entails very high precision ratio setting, which is facilitated by the low power input to the electronic amplifier. These input circuits have been designed so that they allow consistent setting of the cut lengths with errors well below 0.2 per cent.

The high amplification obtainable with an electronic amplifier enables a large correcting effort to be made with a very small deviation from the set ratio. In such a high accuracy system the measures needed to secure stability are simplified by the ease of mixing signals in an electronic amplifier.

Combined with the high accuracy, it is possible to obtain a very high rate of response when using electronic amplifiers, and this is especially necessary in the control of a flying shear. Under certain conditions of cutting, the speed control has to withstand regular impact disturbances up to twice a second.

A second purpose of the electronic gear is to provide more accurate acceleration control. The magnavolt acceleration control and the electronic control operate together, but the electronic control will determine the value of the current in the shear motor armatures by virtue of its greater sensitivity and rapidity of action. This provides a matched acceleration and so minimises the required skill of operators.

Features of Electronic Amplifier

When this equipment was designed it was considered necessary to give it a form of construction more suitable for industrial use and so modify the usual technique for radio receiving sets. The special features of this equipment can be summarised as follows :—

1. The components are chosen for their stability and accuracy of value over long periods so as to give the highest possible reliability.
2. The resistances and condensers are supported on tag strips and all the wiring is fully insulated and numbered.
3. All components including valves are conservatively rated so as to ensure a long life. The equipment described has now operated for over 6,000 hours without any valve replacements.
4. The power supplies are valve stabilised to ensure freedom from drift and independence of supply variations.
5. Special circuit arrangements are used to ensure freedom from external disturbances which might otherwise affect the very sensitive circuits.
6. The output of the electronic gear is injected into the magnavolt circuit in such a way as to correct the speed control without having to supply any appreciable power.

Maintenance Facilities

It is necessary to ensure that the time lost due to faults in the electronic gear is kept to an absolute

minimum. This type of gear is comparatively new to industry and it is unreasonable to expect maintenance staffs to locate faults in electronic equipment within, say, two minutes. Prolonged delays, with their consequent cost in loss of production, must be eliminated by suitable design.

The minimization of lost production time due to faults in the operational equipment is accomplished in three stages. Firstly, by interchanging a faulty unit with a sound one, thus obviating the immediate need to locate a fault in the relatively complicated electronic circuits, and so " getting away " quickly ; secondly, by providing the service engineer with as many " tools " as possible to help in the location of the fault ; and finally, by checking the corrected circuit in the unit which then becomes the spare.

In considering the possible faults which might occur, it was felt that the only type of failure likely to take place suddenly was that of a thyratron in the output circuits. Accordingly an alarm circuit was arranged to give warning of thyratron failure, the equipment meanwhile continuing to function but with reduced accuracy. The substation attendant is then able to interchange the spare and operation thyratron chassis in an interval between pieces. This enables the fully accurate control to be reinstated as soon as possible, and avoids any delay due to the need to find a fault.

Once a faulty unit has been placed in the spare position, it is brought under the control of the service engineer through the medium of metering and test switches upon the panel above the electronic units (see Fig. 1). The spare amplifier may be switched on and, by means of test jacks located on the front of each of the electronic units, the current flowing through each of the valves is registered upon the meter provided. By checking these readings against the correct values it is usually possible to isolate the fault to one valve stage in the amplifiers. It is then a relatively easy matter to replace a valve or to check its associated component values against the schematic diagram finally to locate the fault.

Before it becomes safe to regard this fault-corrected unit as functionally correct and capable of replacing the operational unit at a future date, it must be tested under all its operating conditions. For this purpose the output circuit of these spare

Fig. 1. *Electronic control cubicle, showing metering and test switches*

units is connected to a dummy load simulating the actual operational load, whilst the various input circuits to the amplifier are selected in turn by the test selector switch upon the panel, and input signals, analogous to those the amplifier will meet in actual operation, are applied to the amplifier. The effect of these signals upon the output load is recorded by two further meters, one for each set of thyratrons. The amplifier must therefore be subjected to all these test signals, and record the correct results upon these meters, before it is passed as operationally correct. Thus, should more than one fault have developed in the equipment, and the service engineer having found and cleared one, the possibility of neglecting another is obviated.

In certain circumstances, and particularly with reference to valve failures, it is often possible to avoid loss of production by prevention rather than cure. For example, the ultimate failure of a valve

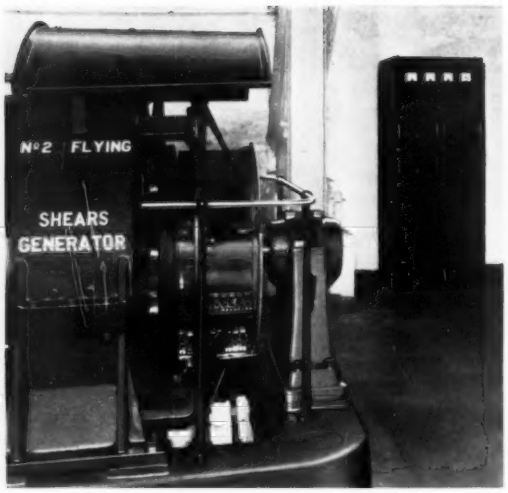


Fig. 2. Electronic control cubicle and associated shear generator

is often preceded by a gradual loss of emission. By continual routine checks of the current flowing through each valve of the operational units, therefore, it is often possible to change a valve, or a unit, before the faulty component has any adverse effect upon the overall performance. For this purpose the test jack metering facility provided for the spare amplifiers is extended to include the operational units as well. Thus the individual valve currents may be checked at regular intervals while the equipment is still in operation, and a defect may be dealt with in time.

Construction

The complete electronic control is built as a self-contained unit in a sheet steel cubicle approximately 7 ft. high, 3 ft. wide and 2 ft. deep, as in Fig. 2. The cubicle is in three sections. The top section accommodates the metering and switching facilities for test purposes, the centre section houses the electronic control units, and the bottom section accommodates auxiliary equipment in the form of contactors, transformers, incoming terminal connections, etc.

The centre section of the cubicle contains the two sets of electronic control equipment, the operational units on the right and the spare units on the left. Each of the two equipments consists of two units. The top unit accommodates the thyratron output valves and associated equipment, and the second unit houses the hard valve control amplifiers and power supplies.

Each of these units consists of a chassis with valves and large components mounted on the top, and with the small components and wiring beneath. All external connections are brought in through self-aligning plugs and sockets fitted at the rear of the chassis. The whole chassis is mounted on runners, which allows easy withdrawal of the units for service purposes or interchange of a faulty operational unit with a spare one. This is shown in Fig. 3, where one of the spare units has been racked out in readiness for replacing a faulty operational unit.

Fig. 3. Electronic control cubicle with one unit withdrawn

High Voltage Switching Stations Incorporating Air-blast Circuit Breakers In Blockhouses

By J. H. C. PETERS, B.Sc., A.M.I.E.E., Sales Manager, Switchgear Department.

THE TYPE OF substation described in this article is one which, although largely built on conventional lines, embodies certain novel features which make it very attractive for major switching stations on high voltage networks, operating at such pressures as 33 and 66 kV.

Briefly, it consists of an outdoor substation with indoor air-blast circuit-breakers mounted in small brick-built blockhouses, the connections being taken through the roof of the blockhouse by bushings, the inner ends of which provide accommodation for current transformers. The remainder of the high voltage gear is located out of doors.

The main attraction of this type of substation lies in the fact that it combines most of the advantages of indoor gear with the economical and financial advantages of outdoor equipment. The circuit-breakers are located indoors and therefore can be inspected and maintained in full comfort in all weathers, at the same time disposing of the problems of weather-proofness associated with outdoor breakers and the remote, but by no means negligible, risk of oil fires and explosions associated with indoor oil and compound filled gear. The overall cost of the station is very little, if any, more than that of a conventional substation incorporating outdoor oil circuit-breakers, and considerably less than that of an indoor switch-house.

General Arrangement Details

The general arrangement of a single busbar substation of this type is shown in Fig. 1, which shows a 66 kV substation with two incoming lines, a bus section and two transformers, with space for

Fig. 1. View of 66 kV blockhouse substation supplying the factory of British Nylon Spinners Ltd.

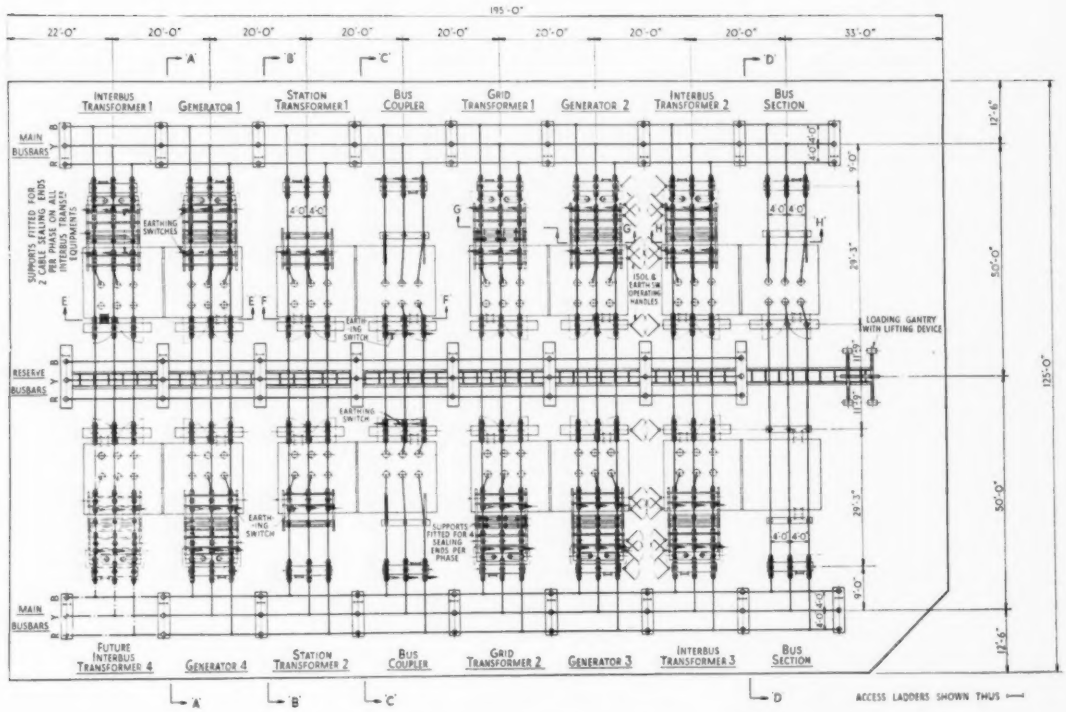


Fig. 2. Layout of 33 kV 1,500 MVA blockhouse substation

a third, feeding the factory of British Nylon Spinners Ltd., in South Wales. The arrangement of this station is conventional in every way except that the air-blast circuit-breakers are mounted in blockhouses, which house one breaker each.

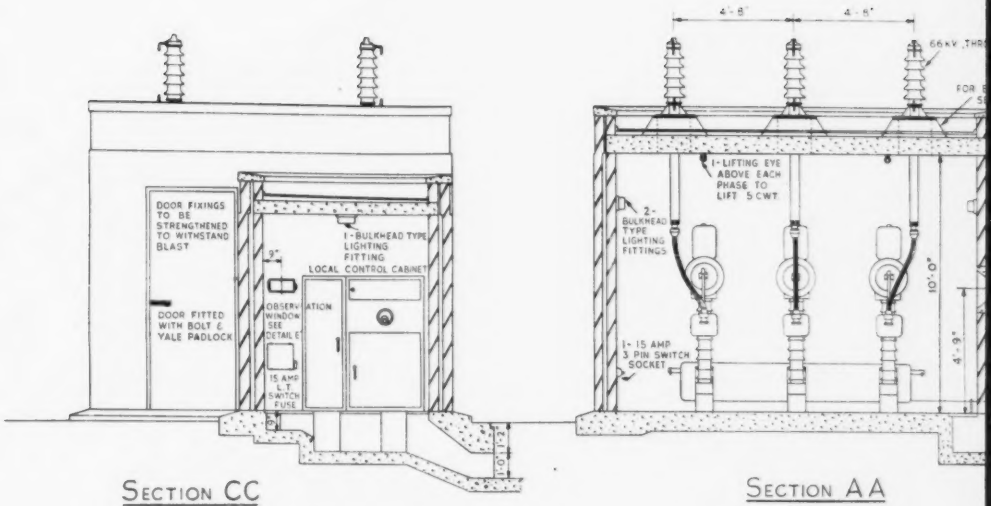
The busbars and isolator supporting structures are of pre-cast concrete, easy to erect and pleasing in appearance. The blockhouse for the third transformer breaker was installed in the first place to facilitate extension at a later date.

Duplicate busbar layouts can be made in the conventional way with two straight lengths of busbar with the blockhouses between them, or in E formation as in Fig. 2 which shows the layout plan for the 33 kV main switchgear at a power station in the North of England. The two outer limbs of the E comprise the main busbar, the ends being joined through the bus section circuit-breaker. The middle leg is the reserve bar and the blockhouses are arranged in two rows between the reserve bar and either section of the main bar. This arrangement gives a very compact and neat layout.

Standard type isolators and busbar construction are used throughout and the feeder side of the breakers can be taken out at low level below the busbars by means of cable. Where overhead lines are connected to feeder breakers, this can be done either direct on to the feeder isolators from the line towers, or by means of short lengths of cable. Fig. 3 shows the end view of the 66 kV main switchgear at the Upper Boat Power Station in South Wales.

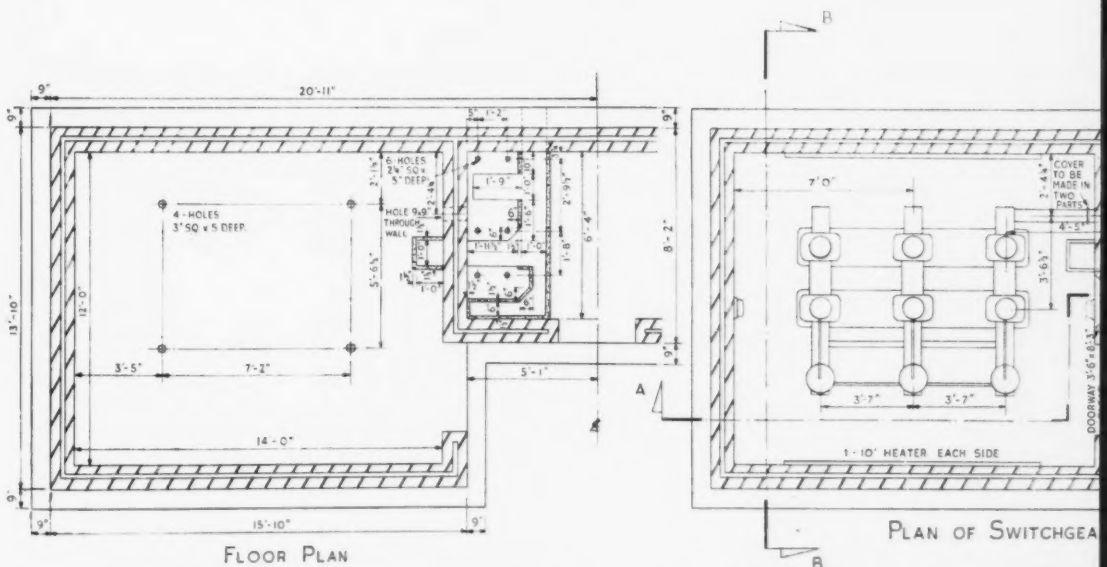
Blockhouse Arrangement

Fig. 4 shows a 33 kV, 1,000 MVA air-blast circuit-breaker in the blockhouse with the through bushings, and ring type current transformers located on them. Flexible stranded copper leads connect the breaker terminals to the bushings.


DOOR FIXINGS TO BE STRENGTHENED TO WITHSTAND BLAST
DOOR FITTED WITH BOLT & YALE PADLOCK
1-BULKHEAD TYPE LIGHTING FITTING LOCAL CONTROL CABINET
OBSERVATION WINDOW SEE DETAIL E
15 AMP L.T. SWITCH FUSE
4'-8"
4'-8"
1-LIFTING EYE ABOVE EACH PHASE TO LIFT 5 CWT.
2-BULKHEAD TYPE LIGHTING FITTINGS
1-15 AMP 3 PIN SWITCH SOCKET
10'-0"
4'-9"

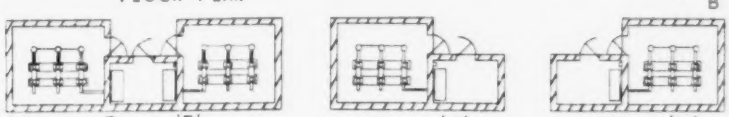
SECTION CC

SECTION AA



FLOOR PLAN

PLAN OF SWITCHGEA



DETAIL 'F'

DETAIL 'G'

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① DOUBLE BLOCKHOUSE AS
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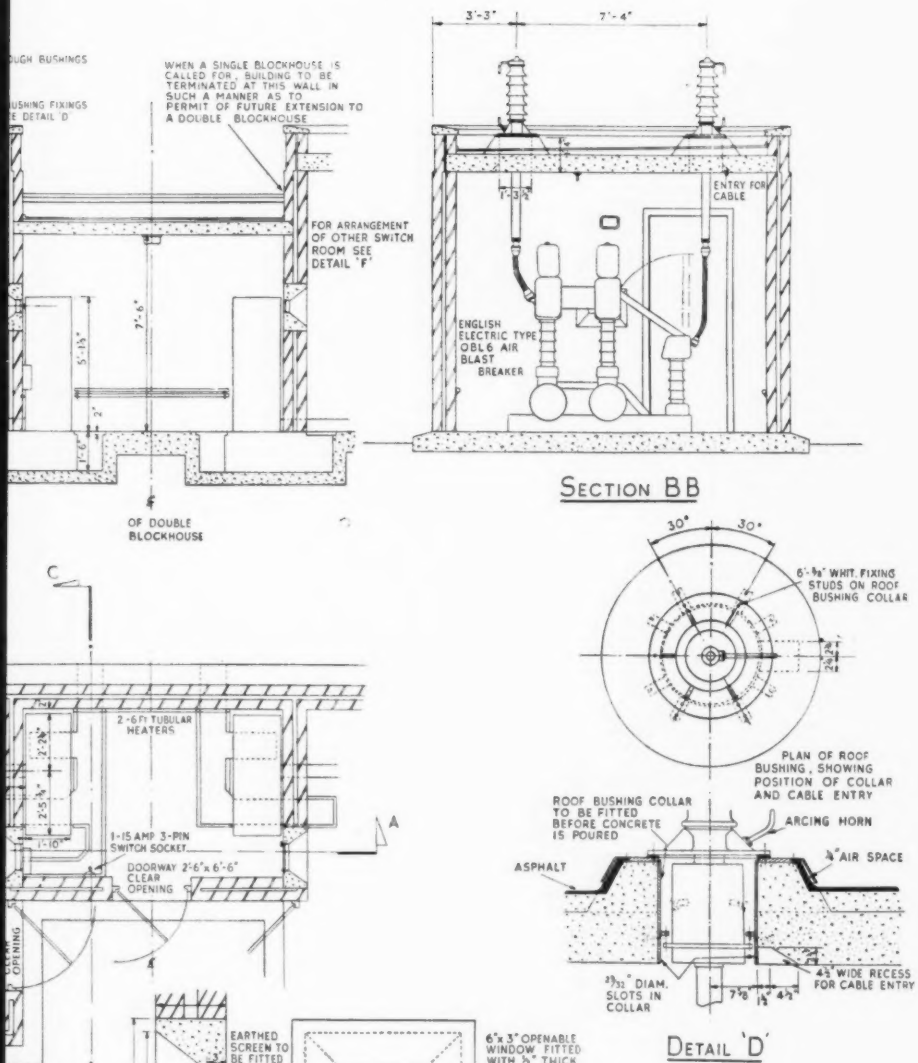
WHEN A SINGLE BLOCKHOUSE IS CALLED FOR, BUILDING TO BE TERMINATED AT THIS WALL IN SUCH A MANNER AS TO PERMIT OF FUTURE EXTENSION TO A DOUBLE BLOCKHOUSE
FOR ARRANGEMENT OF OTHER SWITCH ROOM SEE DETAIL 'F'
OF DOUBLE BLOCKHOUSE
ENTRY FOR CABLE
ENGLISH ELECTRIC TYPE OBL 6 AIR BLAST BREAKER
SECTION BB
6'-9⅛" WHIT. FIXING STUDS ON ROOF BUSHING COLLAR
PLAN OF ROOF BUSHING, SHOWING POSITION OF COLLAR AND CABLE ENTRY
ROOF BUSHING COLLAR TO BE FITTED BEFORE CONCRETE IS POURED
ARCING HORN
¾" AIR SPACE
ASPHALT
DETAIL 'D'
2-6FT TUBULAR HEATERS
1-15 AMP 3-PIN SWITCH SOCKET
DOORWAY 2'-6" x 6'-6" CLEAR OPENING
EARTHED SCREEN TO BE FITTED BEHIND WINDOW
6" x 3" OPENABLE WINDOW FITTED WITH ½" THICK ARMOUR GLASS
DETAIL 'E'
DETAIL 'F'
DETAIL 'G'
AS DETAIL 'H'

Fig. 6. Arrangement of blockhouse with 66 kV air-blast breakers (South Wales Electricity Board)

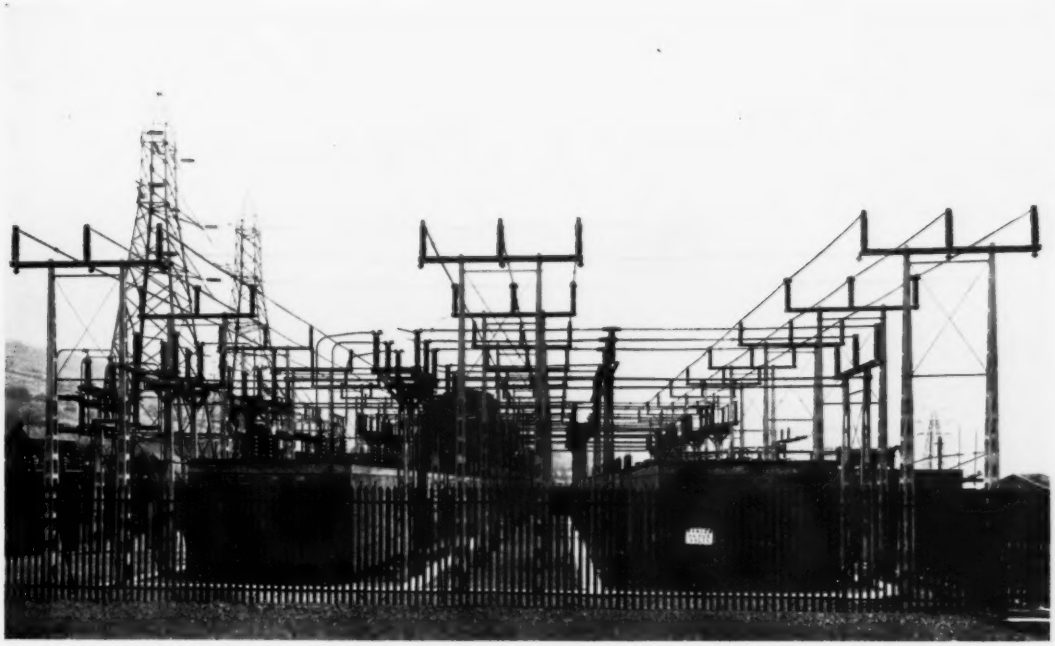

Fig. 3. End view of 66 kV blockhouse substation showing busbar arrangement

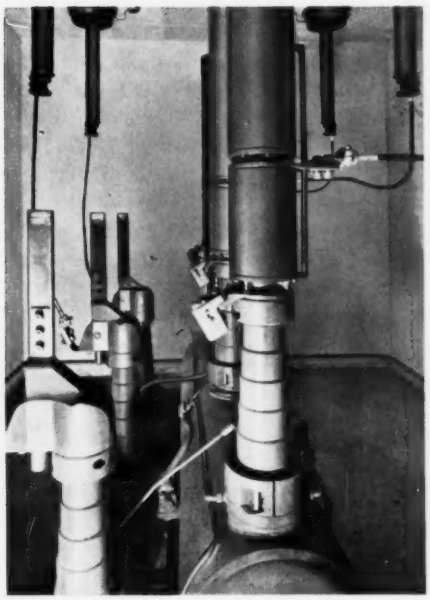

Fig. 4. 33 kV air-blast circuit-breaker in blockhouse

Fig. 5. 66 kV air-blast circuit-breaker in blockhouse, showing local operating cabinet

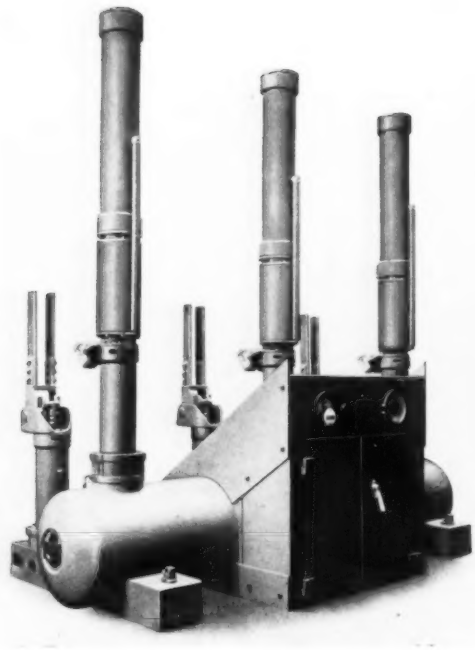

Fig. 7. 33 *kV* 1,500 *MVA air-blast circuit-breaker*

Tubular heaters are fitted in the blockhouse and vents are provided to relieve the pressure when the breaker operates. Adequate space is provided for inspecting and dismantling the breaker.

The blockhouse is divided into two compartments. In one of these is the breaker and all the live connections and in the other the local control equipment, and if desired the relay panel, though this is more usually located in the control room.

The breaker compartment door is fastened by a Castell lock, the key for which can be obtained only when the isolators adjacent to the breaker are open and the breaker is 'dead'. The other compartment which houses control gear only can be visited at any time by a responsible engineer who has the key to the blockhouse door.

Fig. 5 shows a 66 kV, 1,500 MVA air-blast breaker in a blockhouse together with the local control cabinet in the outer compartment.

The local cabinet houses the control valves, the low pressure lockout device, pressure gauge, local control switch, local/remote control changeover switch, incoming and outgoing air piping, together with stop valves, non-return valves etc., in short, all the air supply and control equipment for the breaker together with the terminal boards and multicore cable glands. As already noted, all this equipment is accessible with the breaker 'alive'. The inside of the local cabinet is shown in Fig. 9 which depicts a 33kV, 1,500 MVA air-blast circuit-breaker with the control cabinet doors open.

The roof bushings are of the condenser type, the indoor portion being suitable for housing the current transformers, and the outdoor portion being fitted with porcelain weather sheds with solid filling between the sheds and the bushing itself. On 33 kV systems it is usual to provide bushings of at least 44 kV insulation level, and in exceptional cases 66 kV bushings are supplied. Roof fixing collars are provided and built into the blockhouse roof so that the whole arrangement is made thoroughly rainproof.

Fig. 6 shows the latest arrangement of blockhouse as used by the South Wales Electricity Board. This is built either as a double blockhouse to house two breakers with an intermediate control compartment, or as a single blockhouse which can be extended later to the double construction.

Air-Blast Circuit-Breakers

Fig. 7 shows a 33 kV, 1,500 MVA air-blast circuit-breaker as used in a substation of this type. The local control cabinet is mounted on the front of the breaker, forming part of the breaker compartment partition, and is thus accessible

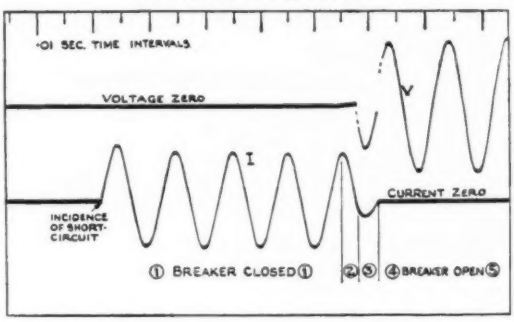

Fig. 8. *Oscillogram showing operation of air-blast circuit-breaker*

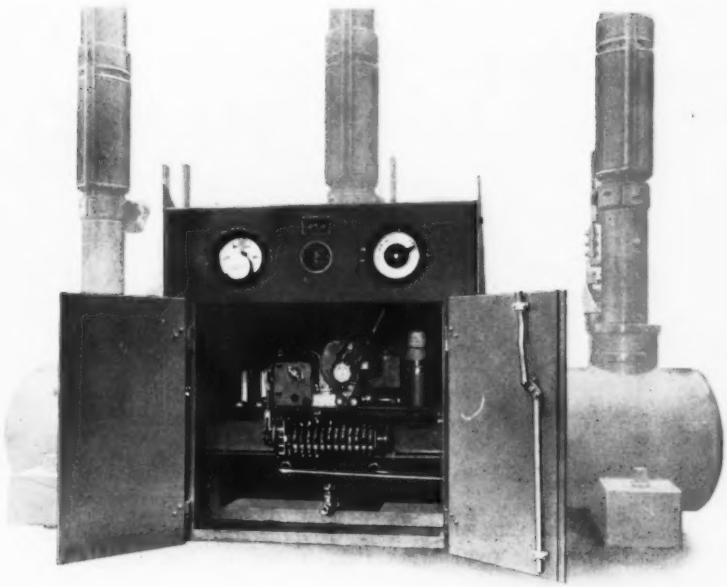

Fig. 9. 33 *kV*, 1,500 *MVA air - blast circuit - breaker, showing operating cabinet*

without going into the live compartment.

The breaker consists of three interrupters, one per phase, mounted on a common solid-drawn air receiver, together with a make-switch, or sequential isolator, and its drive.

The receiver is one solid-drawn forging, and welding is only used for attaching the exterior fittings. Ample inspection holes are provided at each end and the inside is painted with white bitumastic paint. It is designed very liberally. This arrangement is acceptable to all leading insurance companies and the question of periodic hydraulic tests on site does not arise.

At the base of each interrupter column is a blast valve, all three of which are operated simultaneously from the control valve located in the local cabinet.

The interrupter itself is housed in the middle insulator and consists of a butt type contact sealing off the throat in the fixed contact. When the blast valve opens, the air forces the moving contact away from the throat in which the arc is drawn and held on special arcing tips. The pressure air escapes to atmosphere through the throat which is completely scavenged and raised to its maximum dielectric strength by the first current zero.

A second gap on the exhaust side of the fixed contact then breaks down, switching a non-inductively wound linear resistor in parallel with the main gap. This arrangement enables the

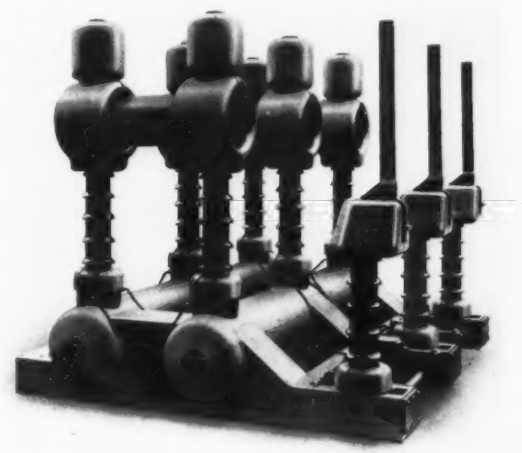

Fig. 10. 66 *kV*, 1,500 *MVA air-blast circuit-breaker*

breaker to deal with much higher levels of short-circuit current than could be handled without it, as the resistance protects the main gap and damps the re-striking voltage transient occurring across it.

The resistance current is comparatively small and being in phase with the voltage is easily extinguished by the follow up of pressure air at its first zero. Thus the total arcing time of the breaker is in the neighbourhood of $\frac{3}{4}$ cycle—see Fig. 8. The arc products are then swept into the cooler and the sequential isolator opens automatically, cutting off the air supply.

The interrupter contacts then reset and the breaker can be closed by driving home the make-switch by means of the closing control valve which supplies air to the make-switch closing cylinder.

Owing to the fact that the arc suppressing effort is, unlike that in the oil circuit-breaker, independent of the magnitude of the arc, the arcing time is the same throughout the range from magnetising to fault currents, and the total break time of the circuit-breaker is three cycles maximum.

The foregoing will serve to demonstrate the consistent behaviour of the breaker over the entire current range, and the very short arcing time ensures that contact burning is negligible. In practice there is no need even to inspect an air-blast circuit-breaker after it has interrupted a heavy fault, still less to do any contact maintenance on it.

As an example of this, on one occasion six faults were deliberately put on one phase of a breaker for the purpose of making certain system measurements, and when the breaker was stripped afterwards, it would have been impossible to tell from the condition of the contacts to which phase the fault had been applied.

Fig. 9 shows the 33 kV breaker with the control cabinet doors open showing the control valves, air pipes, anti-hunting relay, low pressure lockout, low pressure alarm relay, Castell key interlock, emergency trip and auxiliary switches.

The 66 kV, 1,500 MVA breaker is shown in Fig. 10. It consists of two solid-drawn receivers and two interrupters per phase mounted in the

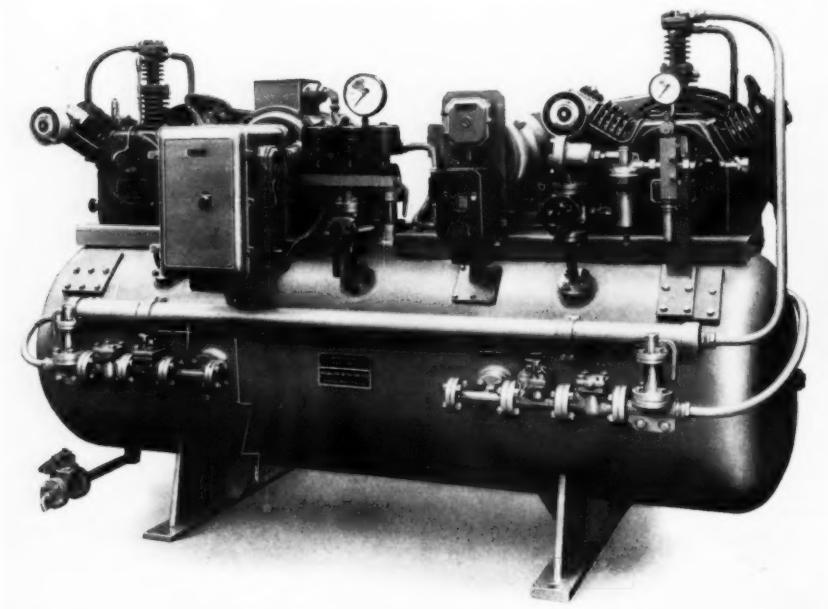

Fig. 11. Compressor equipment complete with all necessary automatic and valve gear

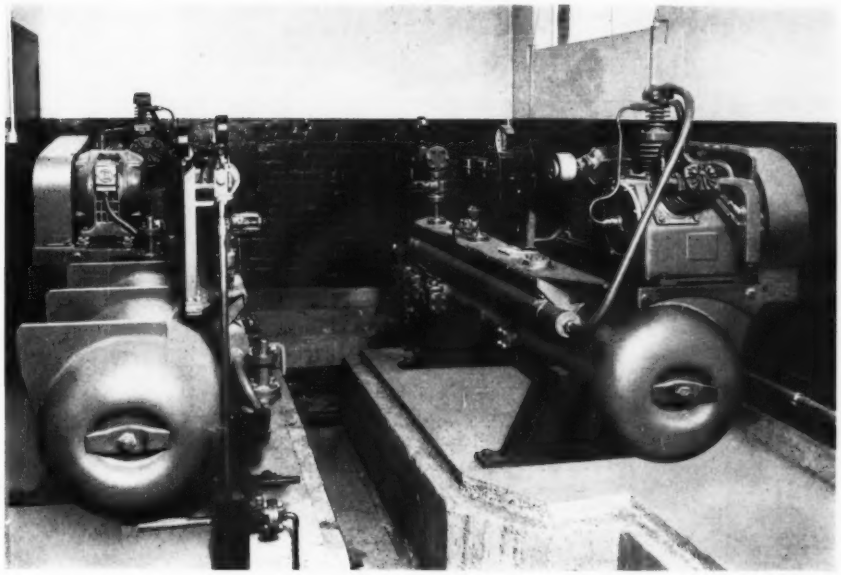

Fig. 12. Compressor house at one of the 66 kV substations

horizontal insulators. This breaker operates on the same principle as the 33 kV breaker previously described except that resistance switching is not used at this voltage as the double interrupter arrangement is capable of handling the maximum conditions without additional help. Stress shields are provided so as to ensure the full impulse strength of 350 kV withstand.

Air Supply

Compressed air is supplied from one or more main compressor equipments, as shown in Fig. 11. The number of main receivers installed depends on the number of breakers and the standby facilities required.

Three-stage compressors driven by automatically controlled motors compress the air in three stages, between which it is passed through coolers, and finally after having traversed the after cooler it is ejected on to the side of the receiver. The sudden expansion and cooling condense the water which falls to the bottom, and air is stored above it at 600 lb/sq. in. at which pressure it is 100 per cent. humid.

From the receiver the air passes through a felt pad filter—which removes any traces of oil vapour —and a stop valve, and thence to an automatic reducing valve which reduces the pressure to that required for the breakers—usually either 250 or 300 lb/sq. in. This automatically halves the humidity, and experience shows that no water is ever found in circuit-breaker receivers, or in the air bus piping.

The air bus piping can be arranged either on the ring main or duplicate busbar principle, and appropriate stop and non-return valves are fitted to each breaker. Thus a fully reliable air supply is assured.

The high pressure pipe fittings on the compressor set are British Ermeto type in which a steel ring inside a conical union joint bites into the pipe, and these have proved to be thoroughly reliable. Those on the low pressure side in the pipe lines are Yorkshire type with solder rings incorporated. When fitting these it is only necessary to clean the parts and apply heat, when the solder ring inside melts and fills up the joints. This arrangement has been found to give excellent results, even in such climates as Southern India.

The whole process of air storage and supply is automatic. The reducing valve operates automatically to refill the receiver of a breaker after it has operated, and automatic pressure switches start up and shut down the motors according to the requirements in the main receiver.

An alarm switch is fitted in case anything fails and the pressure falls below a certain level.

Alarm switches are fitted to the breaker receivers and operate if the pressure stays below lockout level for a period longer than is required for normal refilling. Fig. 12 shows a typical compressor room fitted with two compressor sets each with one compressor. The clean layout is noteworthy, all accessories being mounted on brackets on the receivers themselves.

With all these precautions and the experience of years in the field, it has proved possible to make a completely reliable air supply system.

Application

The particular application of this type of substation is for major switching stations on 33 kV and 66 kV systems for such purposes as main power station switchgear, intake points from the Grid or main step-down substations. Such substations generally have a fair number of circuits and require a high level of short-circuit capacity.

For ordinary distribution substations with only a few circuits and a breaking capacity level of 500 MVA or less, the use of conventional outdoor dead tank type oil circuit-breakers is recommended, but for larger installations with ratings of 750 MVA and above, the blockhouse substation has a great deal to commend it.

On a number of such installations serious consideration is often given to indoor gear, but the blockhouse station, by virtue of combining the facilities of indoor circuit-breakers with the low cost of an outdoor substation, very often provides the most economic answer to the problem.

The reasons for this will be seen in the following two sections.

Costs

To complete the description it is necessary to give

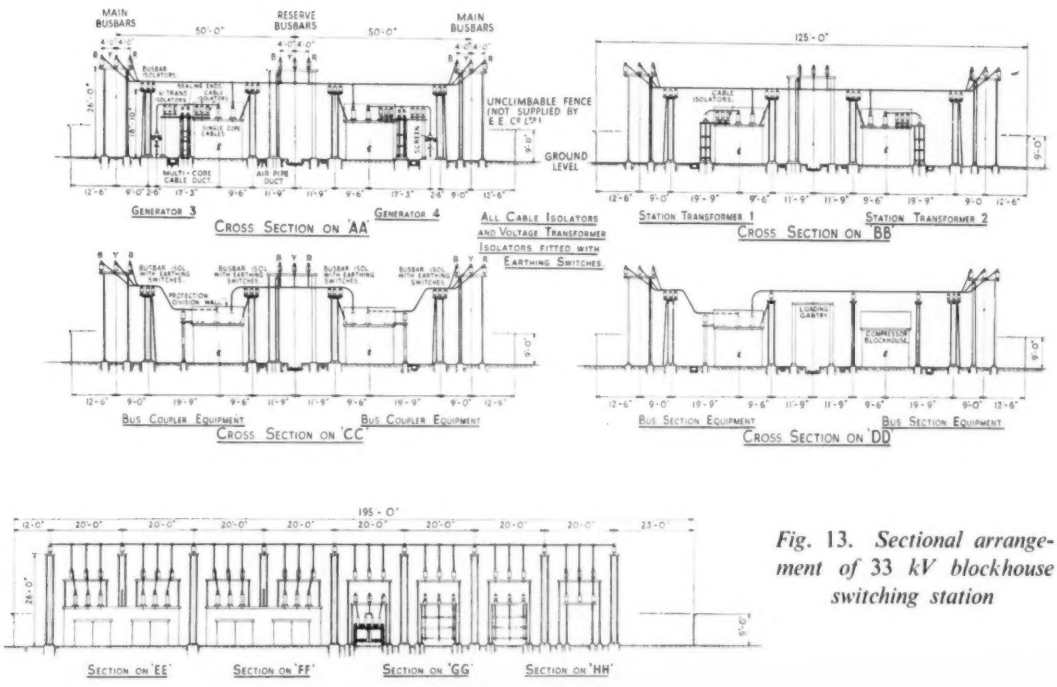

Fig. 13. Sectional arrangement of 33 kV blockhouse switching station

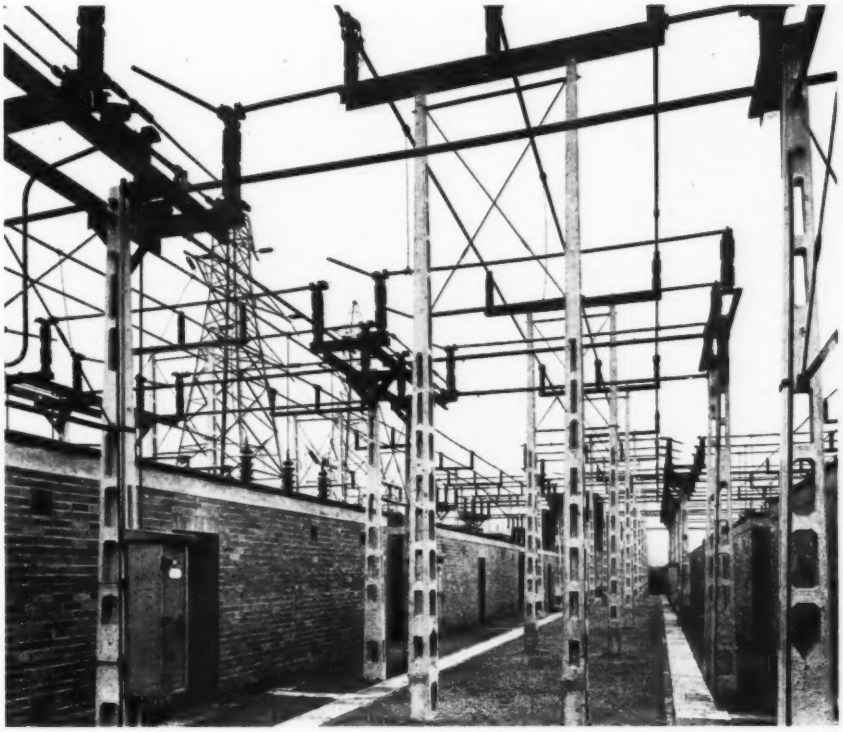

Fig. 14. *View of 66 kV blockhouse substation at Upper Boat Power Station*

a relative cost analysis for a blockhouse air-blast switching station as compared with a conventional outdoor substation employing oil circuit-breakers, and an indoor switch-house with metalclad compound filled gear. Such a comparison must, of course, be approximate as certain factors vary with site conditions, but in general the position can be summed up on the following lines :—

Firstly, it should be stated that the blockhouse air-blast type will not be economical for ratings below 750 MVA and its application is undoubtedly for the major switching stations at or above this rating, for which the comparisons apply.

Dealing next with the conventional outdoor substation employing oil breakers, the space required is almost exactly the same and the electrical equipment supplied is the same except that the outdoor oil breaker is replaced by an indoor air-blast breaker and six roof bushings. Reference to Fig. 13 will show that some of the outdoor gear, e.g., the cable isolators, can be mounted on the blockhouses and this could, of course, be extended quite easily to the busbar isolators.

This brings about a saving in structures with a consequent saving on footings. The oil circuit-breaker rafts and pebble pits are replaced by the blockhouses, which are the chief source of extra cost of this type of substation. Taking everything into consideration on the whole station, the extra cost of a blockhouse station over a straight outdoor station is of the order of 3 to 4 per cent., which is a very small price to pay for the advantages and facilities of this construction.

Coming now to the indoor switch-house, a definite comparison of equipment is impossible. In place of the open type gear, enclosed metalclad oil and compound filled gear is supplied and this in itself costs considerably more than the open type outdoor gear, the difference increasing with

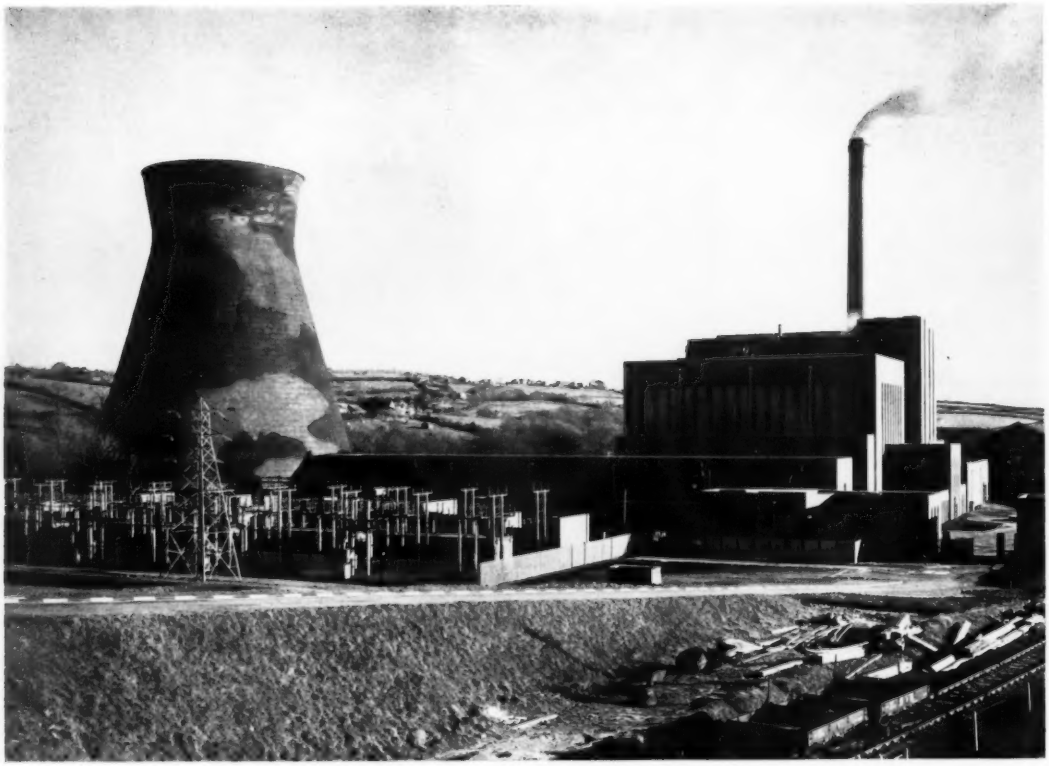

Fig. 15. General view of Llynfi Power Station showing 66 kV blockhouse substation in the foreground

the breaking capacity rating. In addition the building and civil work for the indoor gear is very much more expensive than the comparatively cheap civil work for a blockhouse station, quite apart from the provision of oil drainage and fire fighting equipment necessary to protect the indoor oil-filled gear. Against this the space required for the indoor arrangement is very much less than for the outdoor—sometimes as low as one-third. In some circumstances this may be the determining factor where space is not available or land very expensive, but very often space is available at no extra cost or the land is comparatively cheap, and neglecting any increased costs due to this factor, an overall saving of from 10 per cent. to 40 per cent. can be made by installing blockhouse air-blast gear in place of indoor metalclad gear.

Thus, consideration of the blockhouse air-blast arrangement is very well warranted where circumstances permit of its use.

Advantages

Many advantages can be claimed for this arrangement, which can be summarised as follows :

(1) It combines most of the advantages of indoor gear, with the lower prime cost of the outdoor switching station.

(2) It incorporates all the well-known advantages of air-blast circuit-breakers, i.e. :—

Elimination of oil fire and explosion risk.
Ease of maintenance and inspection.
Consistent high speed performance over

the entire range of currents up to full short-circuit values.

Suitability for frequent operation with little or no maintenance.

General cleanliness of operation.

(3) Circuit-breakers are housed indoors with consequent extra reliability and ease of maintenance and inspection in all weathers. This is a great advantage for the operating staff.

Experience

Considerable operating experience has been gained over the past eight years with this type of substation. The first commissioned was in 1942 when the main 66 kV switching station at the Upper Boat Power Station in South Wales was put into operation. Fig. 14 shows a general view of part of this station. At the same time two substations were installed and in the following year a similar switching station forming the main switchgear at Llynfi Power Station (Fig. 15), and several more major substations, were built.

These switching stations were installed to control power from the generating stations for supplying important factories erected in South Wales for the production of war material, and thus reliability was the key requirement which they have completely fulfilled. The result of experience with these stations has been that all the main 66 kV substations in that area recently commissioned for giving supply to such important projects as the big new steel works and aluminium works, the only nylon yarn factory in the country, and many other projects, are of this type, employing " English Electric " air-blast circuit-breakers.

In addition, very successful service has been given for over six years by the 33 kV main Grid substation at Sundon, near Luton, which has recently been extended to 12 circuits, and the main 33 kV, 1,500 MVA switchgear at Westwood Power Station, Wigan, is in course of erection. The spacing and insulation of the outdoor portion of this equipment is designed at 66 kV level to guard against atmospheric pollution.

Thus it will be seen that the principle has been well tried out and proved under onerous service conditions and is worthy of serious consideration when deciding upon the design of new major switching stations, in view of its many advantages.

Acknowledgments

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